CHAPTER 4. POLLUTANT SOURCE ANALYSIS

4.1 Introduction

The purpose of a TMDL pollutant source analysis is to inventory and describe all sources of pollutants that are impacting the water quality standards of the impaired waterbody. In addition, this chapter describes the processes for delivery of the pollutants and quantifies the pollutant sources within the watershed. The water quality parameters (or pollutants) considered in this Klamath River TMDL source analysis include:

- Temperature;
- Dissolved Oxygen (DO);
- Organic matter – measured as Carbonaceous Biochemical Oxygen Demand (CBOD)[1];
- Total Phosphorus (TP);
- Total Nitrogen (TN); and
- Microcystin.

This analysis draws upon several sources of information and analytic tools to evaluate the various pollutant sources contributing to impairments within the Klamath River. It also draws upon the most current quality assured data available from ongoing monitoring programs conducted by various entities throughout the Klamath Basin. Application of the Klamath River TMDL models (described in Chapter 3) serves as the primary analytic tool for analyzing the water quality impacts of pollutant source loads. In addition, the source analysis incorporates information from published reports, including the approved TMDLs for the Klamath River tributaries listed below:

- Upper Klamath Lake Drainage TMDL and Water Quality Management Plan – Upper Klamath Lakes and Agency Lakes. Oregon Department of Environmental Quality – May 2002;
- Lost River, California Total Maximum Daily Loads: Nitrogen and Biochemical Oxygen Demand to address Dissolved Oxygen and pH Impairments. United States Environmental Protection Agency Region 9. December 2008;
- Staff Report for the Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Loads. State of California North Coast Regional Water Quality Control Board. June 2006;
- Staff Report for the Action Plan for the Scott River Watershed Sediment and Temperature Total Maximum Daily Loads. State of California North Coast Regional Water Quality Control Board. December 2005;
- Salmon River, Siskiyou County, California: Total Maximum Daily Load for Temperature and Implementation Plan. State of California North Coast Regional Water Quality Control Board. June 2005; and

[1] In this TMDL CBOD refers to CBOD- ultimate. The water quality models represent CBOD as organic matter; it is converted to CBOD-ultimate for TMDL calculations.

- Trinity River Total Maximum Daily Load for Sediment. U.S. Environmental Protection Agency Region IX. December 2001.

Pollutant loads for the year 2000 (the model calibration year) are quantified from fourteen geographic areas or entities (called 'source areas') within the California portion of the Klamath River basin. Each source area has a different combination of source categories / processes at work which contribute to the load from that area. ~~There are a total of fourteen source areas.~~ The geographic source areas can be more generally grouped as follows:

- Stateline – waters entering California from Oregon at stateline, which includes the Williamson and Sprague River watersheds, Upper Klamath Lake, the Lost River watershed that drains the Klamath Project area and includes one municipal point source in California, municipal and industrial point sources to the Klamath River in Oregon, and Klamath River waters passing through Keno and JC Boyle Reservoirs. ODEQ's Klamath River TMDL source analysis evaluates the contributions from these discrete sources on the water quality of the Klamath River in Oregon;
- PacifiCorp hydroelectric facilities in California: Copco 1 and 2 and Iron Gate Reservoirs – Copco 1 and 2 Reservoirs are treated as a single source for the purposes of this TMDL;
- Iron Gate Hatchery; and
- Tributaries – Four individual rivers (Shasta, Scott, Salmon, and Trinity Rivers) are included as discrete source areas, while groups of smaller creeks are combined into six additional source areas (stateline to Iron Gate reach tributaries, Iron Gate to Shasta, Shasta to Scott, Scott to Salmon, Salmon to Trinity, and Trinity to Turwar) for this analysis.

~~The Klamath River has historically been referred to as a "river of renewal." This concept which comes from traditional sources (i.e., Tribal) is often used in contemporary comments provided by residents to the Regional Water Board at public meetings. Stephen Most in "*River of Renewal – Myth and History in the Klamath Basin*" (Most 2006) captures both the historical and current ramifications of this concept.~~ The Klamath River is unusual in that it has its origins in a naturally shallow, eutrophic lake, Upper Klamath Lake, which delivers warm water with high levels of nutrients and organic matter to the Klamath River. Due to an increasing stream gradient and inputs from tributaries with water that is both cooler and generally lower in nutrient concentrations, the Klamath River ~~undergoes a renewal process that generally leaves it~~is generally less eutrophic as the river approaches the Pacific Ocean, creating conditions that historically made it one of the most productive cold-water fisheries on the Pacific coast. Because of this unique attribute, traditional (i.e., Tribal) sources have referred to the Klamath River as a "river of renewal." However, d~~D~~espite this unique attribute, current source loads have overwhelmed the historic renewal capabilities of the Klamath River, leading to its impaired status. The intent of the source analysis is to identify and quantify current pollutant source loads, in order to determine the source loads necessary to allow the river once again to be restored through its own unique renewal capabilities.

4.1.1 Pollutant Source Categories

Both point and nonpoint sources of pollution contribute to the water quality impairments in the Klamath River. Land use pollutant source categories impacting Klamath River water quality are identified in Table 4.1. Though difficult to quantify exactly, and sometimes not reflected specifically by watershed models, these land use related nonpoint source categories contribute to water quality impairments in most of the Klamath River source areas. In a basin as large as the Klamath River, where nonpoint sources dominate pollutant loading, it is difficult to precisely quantify loading within source areas from each individual source category. Precise quantification of individual source categories within source areas is not critical because the primary mitigation for nonpoint source loads is not a specific permit limit; rather mitigation is generally based on the use of best management practices that have demonstrated effectiveness to reduce pollutant loads through their application. Therefore the quantitative estimates for the source analysis rely~~ies~~ on source area contribution estimates. The source category assessment is a qualitative analysis intended to provide general direction for the implementation strategy. ~~Though difficult to quantify exactly, and sometimes not reflected specifically by watershed models, these source categories contribute to water quality impairments in most of the Klamath River source areas.~~ The TMDL load and waste load allocations and targets (Chapter 5) are set for source areas at the levels necessary to meet water quality standards in California. The implementation plan (Chapter 6) presents the regulatory mechanisms necessary to control ~~these~~ the major source categories within the source areas and addresses the other source contributions, including the PacifiCorp hydroelectric facilities in California, Iron Gate Hatchery, and suction dredging.

Often, loading from one source category contributes to multiple impairments, as shown in Table 4.1. For example, sediment delivered to the Klamath River from timber harvest related activities and roads can contribute to temperature impairments, but also may contain nutrients that can contribute to DO impairment through biostimulatory effects. Another example of a combined effect is the alteration of riparian functions, such as the degradation of vegetation that provides shade to a waterbody. Not only can this lead to an increase in the temperature load to the water column, it also increases light levels that can increase biostimulatory activity, and reduces the capacity of the riparian zone to filter sediment and nutrients.

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Table 4.1: Klamath River Anthropogenic Pollutant Source Categories Impacting Water Quality Parameters of Concern.

Land Use Source Categories Affecting	Temperature	DO	Nutrients	Organic Matter
Wetland conversion		X	X	X
Grazing	X	X	X	X
Irrigated agriculture	X	X	X	X
Timber harvest and sediment	X	X	X	X
Roads	X	X	X	

4.1.2 Natural Conditions Baseline - Background Loads

The starting point for the Klamath River pollutant source analysis involved quantifying natural conditions baseline water quality conditions of the river. The amount of temperature, nutrient, and organic matter loading from natural background sources varies dramatically from one geographic region to another. The TMDL source analysis and allocations recognize and account for the naturally higher background levels of nutrients and organic matter within the upper Klamath River basin in comparison to other ecoregions in California. This higher natural background loading translates into a smaller loading capacity of the river, and less available assimilative capacity to avoid excess heat load, oxygen-consuming substances, and biostimulatory conditions.

As ~~detailed~~ outlined in Chapter 3 and detailed in Appendix 7, the Klamath River TMDL models were applied to characterize natural conditions baseline water quality of the Klamath River. In estimating the natural conditions baseline water quality of the Klamath River, the following characteristics about the Klamath River watershed were incorporated.

The underlying geology in much of the Upper Klamath basin is of volcanic origin. Soils derived from this rock type are naturally high in phosphorus (Walker 2001). Through natural erosion and leaching processes, these soils contribute a high background phosphorous load to Upper Klamath basin waters. In a nutrient loading study conducted by Rykbost and Charlton (2001), monitoring of several natural artesian springs in the upper Klamath basin was characterized by high levels of nitrogen and phosphorus, demonstrating the high natural background loading of nutrients. Upper Klamath Lake has long been noted for its eutrophic condition and demonstrated presence of high levels of organic matter (algae), including nitrogen fixing blue-green algae (Kann and Walker 2001). This nutrient and organic-matter rich Upper Klamath Lake (UKL) water is the headwaters source of the Klamath River.

As described in Section 2.3, Eilers et al. (2004) have identified a clear shift in UKL productivity and species composition in the past 100 years, consistent with large scale land disturbance activities, which can be strongly implicated as the cause of the lake's current hypereutrophic character. These changes also include increased export of nutrients and organic matter from UKL to the downstream waters of Klamath River, contributing to the pollutant loading and water quality conditions that are present today.

In addition, this issue has been previously addressed in the technical report for the Upper Klamath Lake Drainage TMDL (ODEQ 2002). This report includes a basin nutrient mass balance model that represents both existing conditions and an approximation of pre-disturbance natural conditions baseline. Pre-disturbance conditions account for the full nutrient retention / loss capabilities of the former extent of wetlands in the upper basin, and landscape export of nutrients prior to increased delivery of nutrients to UKL from silvicultural and agricultural operations. The Upper Klamath Lake Drainage TMDL was based on a number of model years and scenario assumptions providing a range of TMDL compliant conditions. The Klamath River TMDL natural conditions baseline model scenario uses the median of this range of compliance conditions as the boundary condition for source loading to Link River from UKL. A more detailed description of the modeling and assumptions that went into developing these natural condition baseline boundary conditions is available in the Upper Klamath Lake Drainage TMDL (ODEQ 2002), in ODEQ's Klamath River TMDL technical report, and in Appendix 7.

Within the Klamath Mountains Province of the mid- and lower-Klamath River (Figure 1.4), the underlying geology is not volcanic, and therefore does not tend to have the high levels of nitrogen and phosphorus characteristic of the Upper Klamath basin. Consequently, the tributaries that drain to the Klamath River within this province have considerably lower nutrient concentrations. As a result, the eutrophic condition of the Klamath River generally improves as it flows from the Upper Klamath basin to the Pacific Ocean.

Alkalinity is a measure of the ability of water to neutralize acids. In the natural environment, alkalinity comes primarily from the dissolution of carbonate rocks. Carbonate rock sources are rare in much of the Klamath basin due to its volcanic origin. As a result, the Klamath River has a relatively low alkalinity (<100 mg/L). The low alkalinity provides for a weak buffering capacity of Klamath River water. Photosynthetic activity removes carbon dioxide in the water (in the form of carbonic acid) which increases the water pH (see Section 2.4.2.1 for a discussion of impacts). Natural alkalinity serves as a buffer to minimize the photosynthetically induced increase in pH. In low alkalinity waters such as the Klamath River, this buffering capacity is frequently exceeded and high pH values are observed during daytime hours when photosynthesis is occurring. The large daily variation of pH observed in the Klamath River is caused by photosynthetic activity in the low alkalinity water.

Further exacerbating the effect of the naturally productive and weakly buffered system is the presence of regionally high ambient summer air temperatures, and the resulting high heat load to the shallow and predominantly un-shaded Upper Klamath Lake. These naturally warm waters are the source of the Klamath River. In addition, the east-west aspect of much of the Klamath River also makes it prone to heating, even within the steep gorges of some reaches of the river.

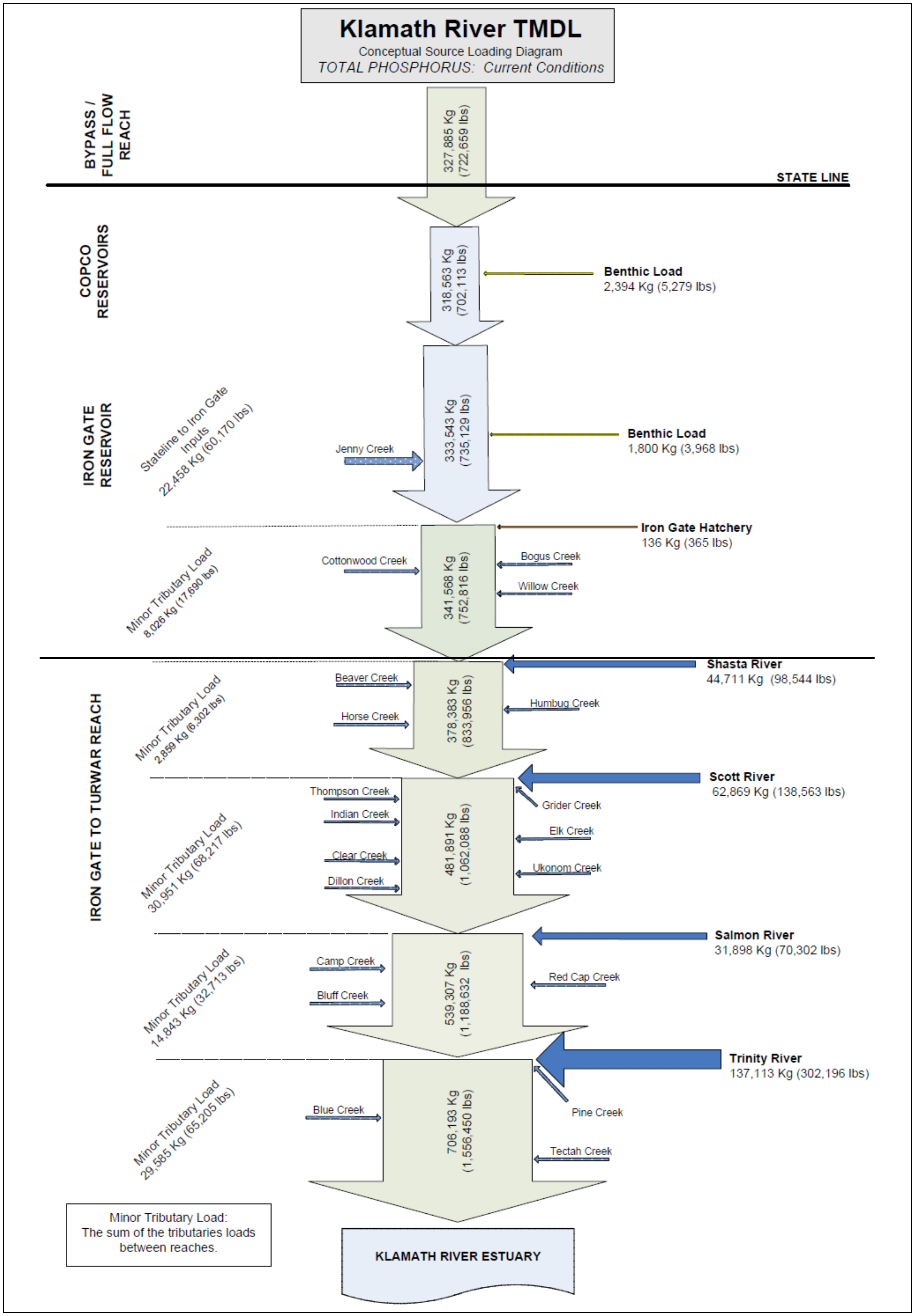
In summary, the solar exposure and seasonally high ambient air temperatures, coupled with the high levels of biological productivity and respiration that are enhanced by the high levels of biostimulatory nutrients, yield large volumes of organic matter, seasonally high water temperatures, daily low dissolved oxygen, and high pH levels. All of these water quality conditions can be extremely stressful to many forms of aquatic life. These natural background heat, nutrient, and organic matter loads to the Klamath River underscore the very limited capacity of the river to assimilate anthropogenic pollutant sources, and the necessity for establishing load allocations that will result in attainment of water quality standards.

4.1.3 Pollutant Source Loads - Overview

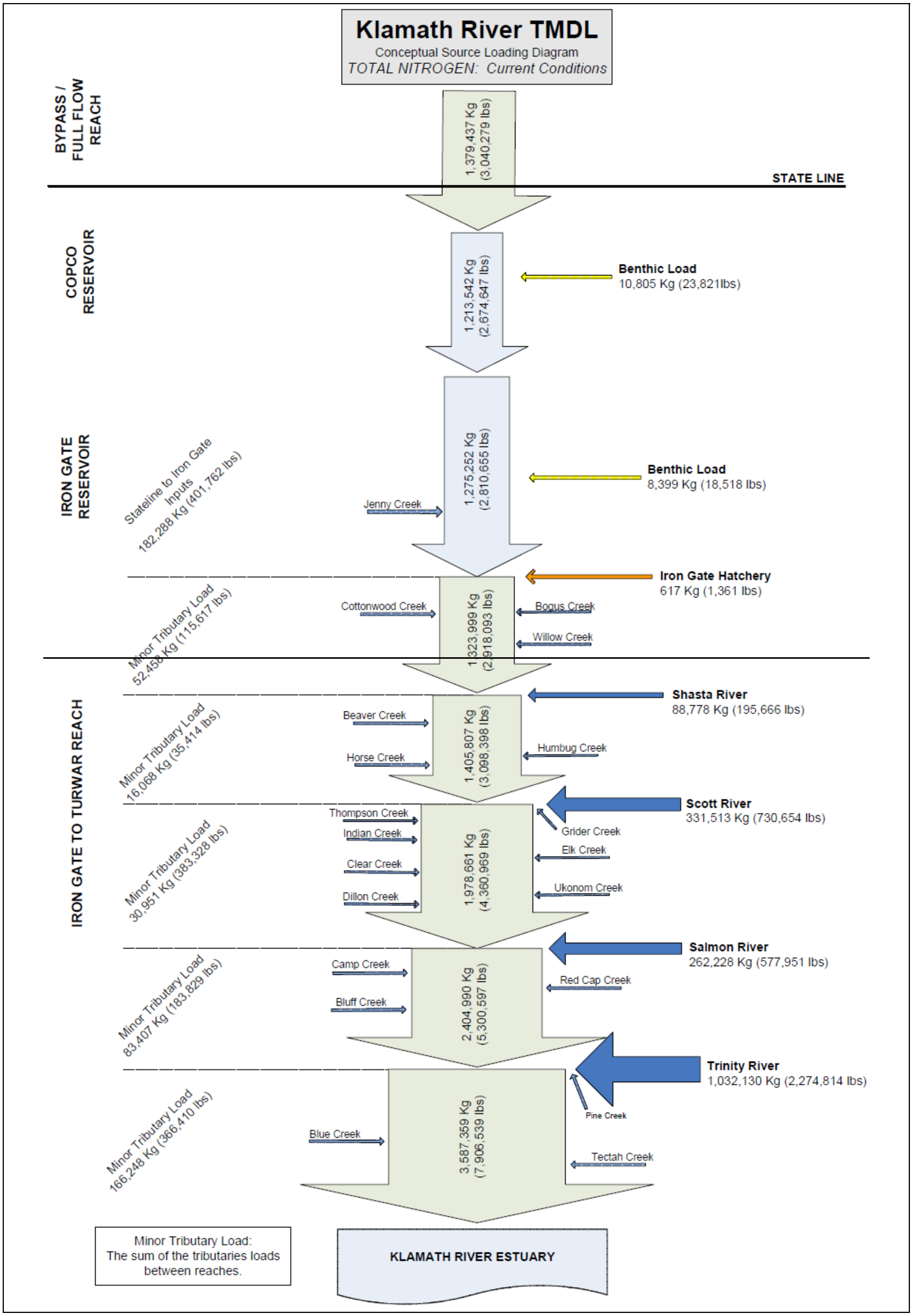
The Klamath River TMDL models were used to calculate loads for the year 2000, and for purposes of the Klamath TMDL, year 2000 loads represent current loading conditions. The cumulative pollutant loads to the Klamath River for the year 2000 are identified in the schematic diagrams below (Figures 4.1, 4.2, and 4.3). These figures provide an illustration or graphical representation of the current cumulative loading to the Klamath River for total phosphorus, total nitrogen, and organic matter (CBOD[2]) from the fourteen source areas within California. Cumulative loads used in this analysis include the total annual mass generated from upstream sources that pass through the assessment location. The analysis represents a mass-balance of loads in California that sums all of the mass inputs and outputs to reaches of the river on an annual basis, and includes within-stream and reservoir dynamics (e.g., losses, retention, and fluxes). The width of a segment arrow is proportional to the magnitude of the loading for that reach. These figures demonstrate that~~, unlike in many other river systems,~~ the Klamath River transports relatively large pollutant loads ~~are larger~~ (~40% of the total load at the mouth of the river) ~~in~~ from the upper ~~half~~ part of the basin across ~~(i.e. inputs at~~ stateline~~)~~. The upper basin is relatively low in water yield and high in concentration compared to the relatively high water yield and low concentration contributions of the lower basin tributaries. The source area loads are also summarized in Table 4.2. Figures 4.1, 4.2, and 4.3 and Table 4.2 provide a comprehensive overview of current loading conditions. For comparison, Table 4.2 also presents estimated annual natural conditions baseline loadings, the current and natural source loading estimates for the critical six month period (May – October) when water quality impairments are generally worst, and the percentage of annual loading associated with each parameter for each source area. The estimates of natural conditions baseline loadings are based on the natural conditions baseline model scenario. The information presented in Table 4.2 is not directly comparable to the information presented in Figures 4.1, 4.2, and 4.3. The vector diagram figures present cumulative loadings, incorporating loss and retention within the reservoirs and river reaches, whereas the table only presents the loads to the river from the source areas.

Given the different units typically used to characterize heat load, vector diagrams and a summary table are not presented to summarize the temperature loads to the Klamath River. The temperature effects from different source areas and source categories are presented in Section 4.2.

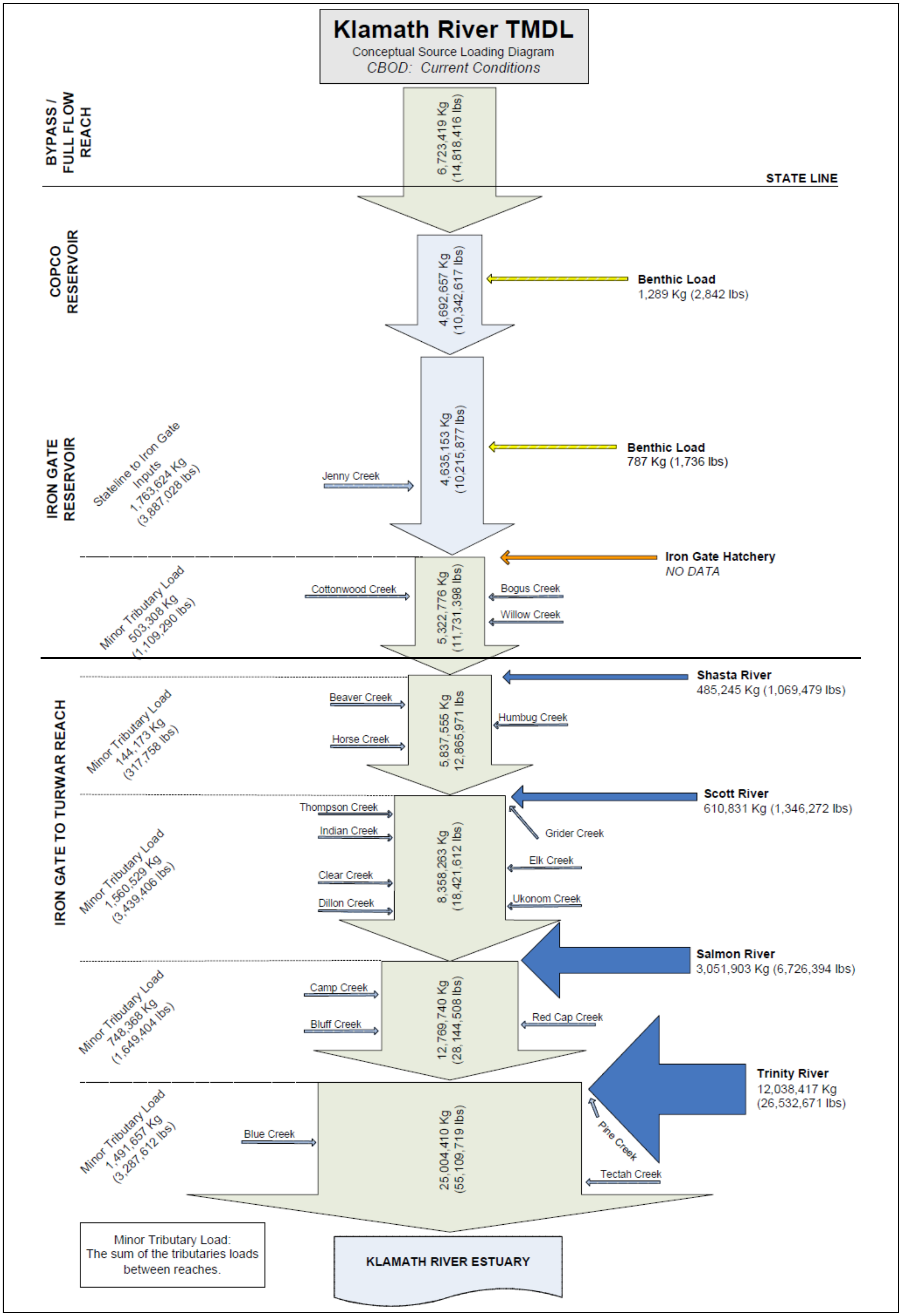
[2] CBOD is a quantitative measure of the amount of dissolved oxygen required for the ~~biological~~ biochemical oxidation of carbon-containing compounds.



~~Figure 4.1: Current Total Phosphours Annual Loading Diagram~~



~~Figure 4.2: Current Total Nitrogen Annual Loading Diagram~~



~~Figure 4.3: Current Organic Matter (as CBOD) Annual Loading Diagram~~

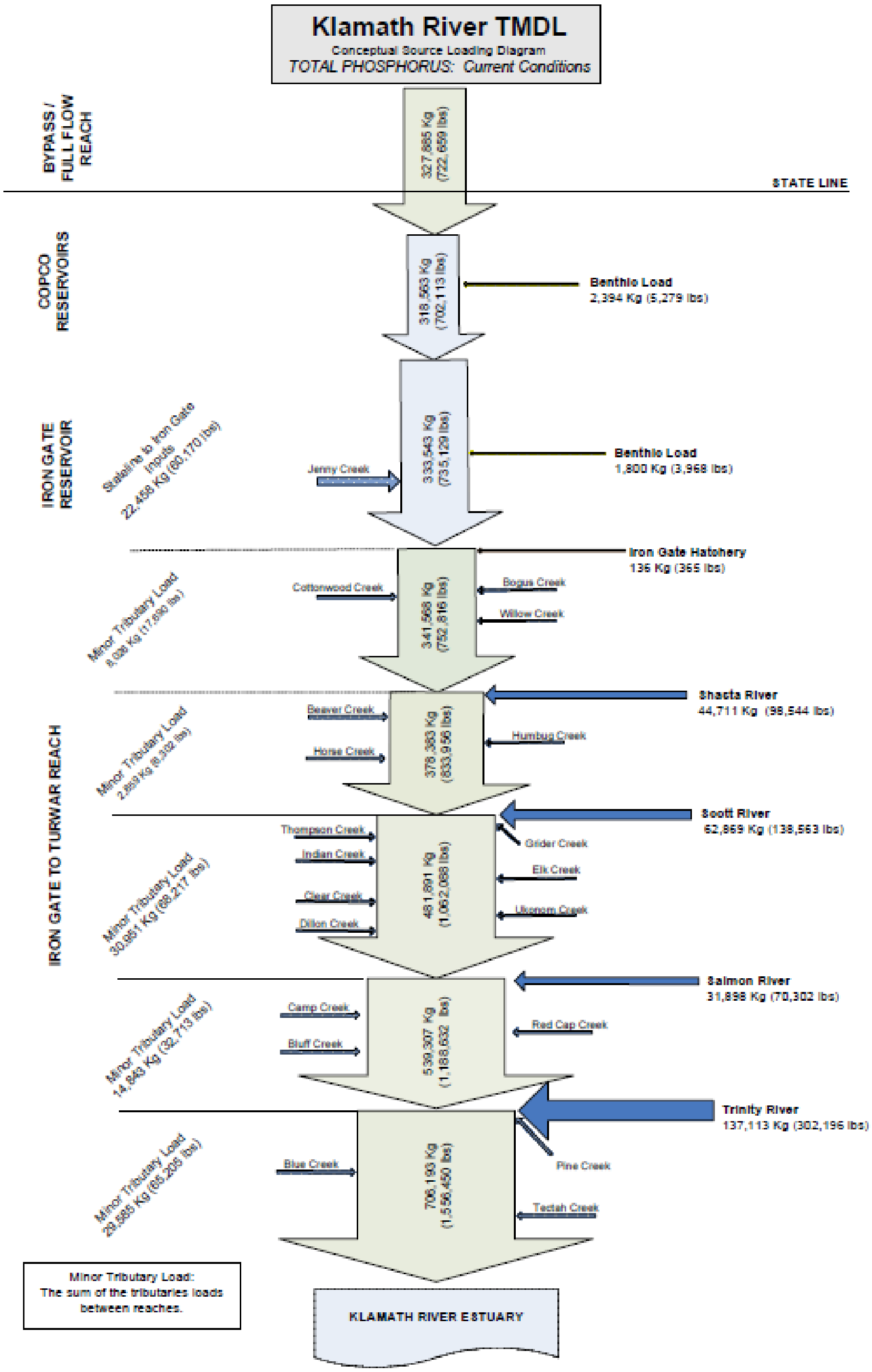


Figure 4.1: Current Total Phosphours Annual Loading Diagram

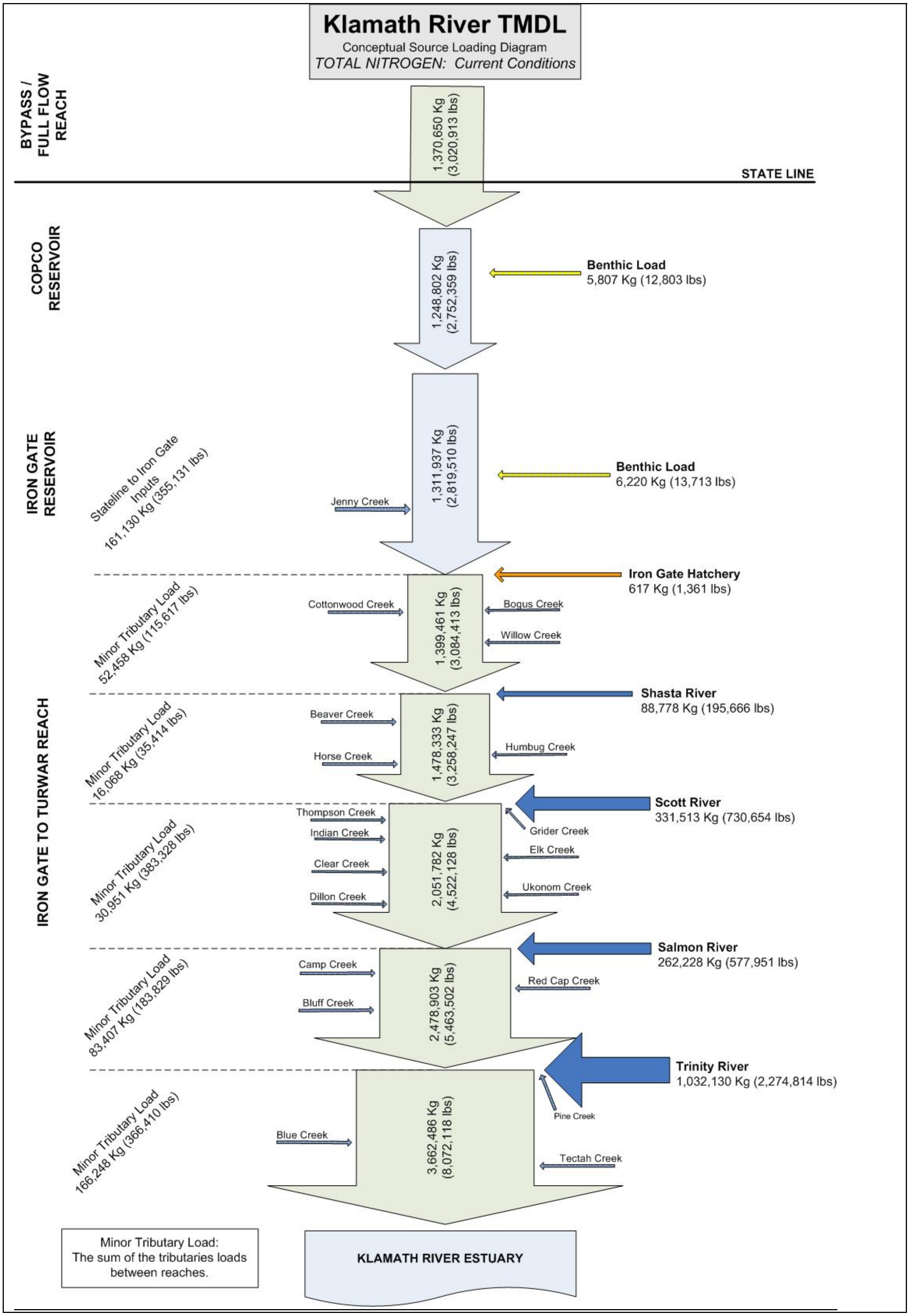


Figure 4.2: Current Total Nitrogen Annual Loading Diagram

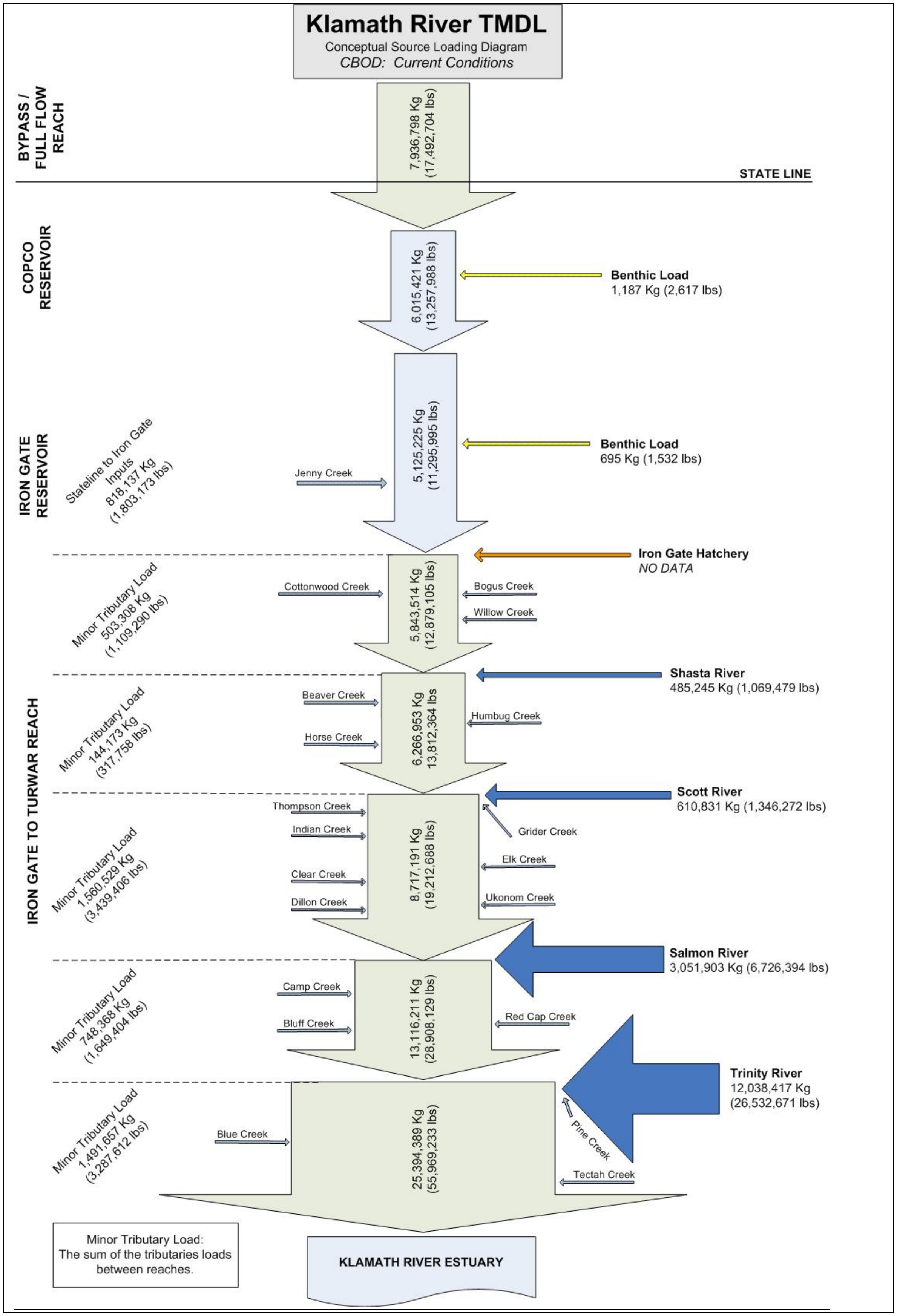


Figure 4.3: Current Organic Matter (as CBOD) Annual Loading Diagram

~~Table 4.2: Current and Natural Conditions Baseline Nutrient and Organic Matter Loadings to the Klamath River in California~~

~~Klamath River TMDL Source Analysis Summary~~										
-		~~Annual Source Loads (lbs.)~~			~~Critical Period Source Loads (lbs.) May - October (six months)~~			~~Current Percent Total Annual Loading~~		
~~Source Area~~		**~~TP~~**	**~~TN~~**	**~~CBOD~~**	**~~TP~~**	**~~TN~~**	**~~CBOD~~**	**~~TP~~**	**~~TN~~**	**~~CBOD~~**
~~Klamath River~~ ~~- Stateline~~	~~Current~~	~~722,659~~	~~3,040,279~~	~~14,818,416~~	~~325,171~~	~~1,393,022~~	~~4,322,249~~	~~45.4%~~	~~36.4%~~	~~23.1%~~
	~~Natural Baseline~~	~~105,538~~	~~1,128,968~~	~~9,126,909~~	~~38,366~~	~~368,455~~	~~2,737,124~~			
~~Copco Reservoir Outlet~~	~~Current~~	~~702,113~~	~~2,674,647~~	~~10,342,617~~	~~320,776~~	~~1,106,286~~	~~2,503,398~~			
	~~Natural Baseline~~	~~104,628~~	~~1,119,334~~	~~8,972,005~~	~~37,458~~	~~358,592~~	~~2,705,469~~			
~~Copco Reservoirs~~ ~~– sediment flux~~	~~Current~~	~~5,279~~	~~23,821~~	~~2,842~~	~~4,941~~	~~22,169~~	~~3,141~~	~~0.3%~~	~~0.3%~~	~~0.0%~~
	~~Natural Baseline~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~			
~~Stateline to Iron Gate inputs~~	~~Current~~	~~60,170~~	~~401,762~~	~~3,887,028~~	~~15,192~~	~~101,436~~	~~981,390~~	~~3.8%~~	~~4.8%~~	~~6.1%~~
	~~Natural Baseline~~	~~60,170~~	~~401,762~~	~~3,887,028~~	~~15,192~~	~~101,436~~	~~981,390~~			
~~Iron Gate Reservoir Outlet~~	~~Current~~	~~735,129~~	~~2,810,655~~	~~10,215,877~~	~~325,308~~	~~980,102~~	~~2,420,586~~			
	~~Natural Baseline~~	~~116,971~~	~~1,244,875~~	~~9,833,815~~	~~42,876~~	~~408,753~~	~~3,106,030~~			
~~Iron Gate Reservoir~~ ~~– sediment flux~~	~~Current~~	~~3,968~~	~~18,518~~	~~1,736~~	~~1,783~~	~~7,719~~	~~1,249~~	~~0.2%~~	~~0.2%~~	~~0.0%~~
	~~Natural Baseline~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~			
~~Iron Gate Fish Hatchery~~	~~Current~~	~~365~~	~~1,361~~	~~no data~~	~~182~~	~~680~~	~~no data~~	~~0.0%~~	~~0.0%~~	~~no data~~
	~~Natural Baseline~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~			
~~Iron Gate to Shasta Tributaries~~ ~~▪ Bogus Creek~~ ~~▪ Willow Creek~~ ~~▪ Cottonwood Creek~~	~~Current~~	~~17,690~~	~~115,617~~	~~1,109,290~~	~~4,697~~	~~30,701~~	~~294,558~~	~~1.1%~~	~~1.4%~~	~~1.7%~~
	~~Natural Baseline~~	~~17,690~~	~~115,617~~	~~1,109,290~~	~~4,697~~	~~30,701~~	~~294,558~~			
~~Shasta River~~	~~Current~~	~~98,544~~	~~195,666~~	~~1,069,479~~	~~33,104~~	~~64,093~~	~~592,149~~	~~6.2%~~	~~2.3%~~	~~0.9%~~
	~~Natural Baseline~~	~~27,284~~	~~80,259~~	~~878,229~~	~~8,916~~	~~26,298~~	~~288,023~~			

Table 4.2: Current and Natural Conditions Baseline Nutrient and Organic Matter Loadings to the Klamath River in California

Klamath River TMDL Source Analysis Summary

-		Annual Source Loads (lbs.)			Critical Period Source Loads (lbs.) May - October (six months)			Current Percent Total Annual Loading		
Source Area		**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**	**TP**	**TN**	**CBOD**
Klamath River - Stateline	Current	717,523	3,020,913	17,492,704	316,898	1,343,967	5,949,442	44%	37%	27%
	Natural Baseline	86,737	866,423	6,498,082	29,281	250,408	1,632,541			
Copco Reservoir Outlet	Current	703,047	2,752,359	13,257,988	315,260	1,109,887	3,539,298			
	Natural Baseline	85,776	859,407	6,449,343	28,024	239,122	1,617,123			
Copco Reservoirs – sediment flux	Current	3,331	12,803	2,617	3,204	13,623	1,432	0%	0%	0%
	Natural Baseline	0	0	0	0	0	0			
Stateline to Iron Gate inputs	Current	90,979	355,131	1,803,173	32,638	116,354	358,945	6%	4%	3%
	Natural Baseline	10,157	94,355	690,994	4,212	34,365	235,163			
Iron Gate Reservoir Outlet	Current	772,016	2,891,510	11,295,995	341,109	1,003,978	2,449,221			
	Natural Baseline	95,493	950,527	7,077,933	31,998	271,542	1,867,382			
Iron Gate Reservoir – sediment flux	Current	365	13,713	1,532	1,646	7,240	1,827	0%	0%	0%
	Natural Baseline	0	0	0	0	0	0			
Iron Gate Fish Hatchery	Current	365	1,361	no data	182	680	no data	0.0%	0.0%	no data
	Natural Baseline	0	0	0	0	0	0			
Iron Gate to Shasta Tributaries ▪ Bogus Creek ▪ Willow Creek ▪ Cottonwood Creek	Current	17,690	115,617	1,109,290	4,697	30,701	294,558	1%	1%	2%
	Natural Baseline	17,690	115,617	1,109,290	4,697	30,701	294,558			
Shasta River	Current	98,544	195,666	1,069,479	33,104	64,093	592,149	6%	2%	2%
	Natural Baseline	52,351	154,406	1,691,081	19,651	57,960	634,790			

~~Table 4.2 (cont.): Current and Natural Conditions Baseline Nutrient and Organic Matter Loadings to the Klamath River in California~~

~~Klamath River TMDL Source Analysis Summary~~										
-		~~Annual Source Loads (lbs.)~~			~~Critical Period Source Loads (lbs.) May - October (six months)~~			~~Current Percent Total Annual Loading~~		
~~Source Area~~		**~~TP~~**	**~~TN~~**	**~~CBOD~~**	**~~TP~~**	**~~TN~~**	**~~CBOD~~**	**~~TP~~**	**~~TN~~**	**~~CBOD~~**
~~Shasta to Scott Tributaries~~ ~~▪ Humbug Creek~~ ~~▪ Beaver Creek~~ ~~▪ Horse Creek~~	~~Current~~	~~6,302~~	~~35,414~~	~~317,758~~	~~1,673~~	~~9,401~~	~~84,348~~	~~0.4%~~	~~0.4%~~	~~0.5%~~
	~~Natural Baseline~~	~~6,302~~	~~35,414~~	~~317,758~~	~~1,673~~	~~9,401~~	~~84,348~~			
~~Scott River~~	~~Current~~	~~138,563~~	~~730,654~~	~~1,346,272~~	~~52,957~~	~~208,948~~	~~1,056,452~~	~~8.7%~~	~~8.8%~~	~~2.1%~~
	~~Natural Baseline~~	~~138,563~~	~~730,654~~	~~1,346,272~~	~~52,957~~	~~208,948~~	~~1,056,452~~			
~~Scott to Salmon Tributaries~~ ~~▪ Grider Creek~~ ~~▪ Thompson Creek~~ ~~▪ Happy Camp Creek / Indian~~ ~~▪ Elk Creek~~ ~~▪ Clear Creek~~ ~~▪ Ukonom Creek~~ ~~▪ Dillon Creek~~	~~Current~~	~~68,217~~	~~383,328~~	~~3,439,406~~	~~12,978~~	~~72,930~~	~~654,360~~	~~4.3%~~	~~4.6%~~	~~5.4%~~
	~~Natural Baseline~~	~~68,217~~	~~383,328~~	~~3,439,406~~	~~12,978~~	~~72,930~~	~~654,360~~			
~~Salmon River~~	~~Current~~	~~70,302~~	~~577,951~~	~~6,726,394~~	~~15,358~~	~~192,412~~	~~1,946,043~~	~~4.4%~~	~~6.9%~~	~~10.5%~~
	~~Natural Baseline~~	~~70,302~~	~~577,951~~	~~6,726,394~~	~~15,358~~	~~192,412~~	~~1,946,043~~			
~~Salmon to Trinity Tributaries~~ ~~▪ Camp Creek~~ ~~▪ Red Cap Creek~~ ~~▪ Bluff Creek~~	~~Current~~	~~32,713~~	~~183,829~~	~~1,649,404~~	~~6,002~~	~~33,726~~	~~302,610~~	~~2.1%~~	~~2.2%~~	~~2.6%~~
	~~Natural Baseline~~	~~32,713~~	~~183,829~~	~~1,649,404~~	~~6,002~~	~~33,726~~	~~302,610~~			
~~Trinity River~~	~~Current~~	~~302,196~~	~~2,274,814~~	~~26,532,671~~	~~56,891~~	~~460,714~~	~~4,780,372~~	~~19.0%~~	~~27.2%~~	~~41.3%~~
	~~Natural Baseline~~	~~302,196~~	~~2,274,814~~	~~26,532,671~~	~~56,891~~	~~460,714~~	~~4,780,372~~			
~~Trinity River to Turwar Tributaries~~ ~~▪ Pine Creek~~ ~~▪ Tectah Creek~~ ~~▪ Blue Creek~~	~~Current~~	~~65,205~~	~~366,410~~	~~3,287,612~~	~~11,972~~	~~67,277~~	~~603,640~~	~~4.1%~~	~~4.4%~~	~~5.1%~~
	~~Natural Baseline~~	~~65,205~~	~~366,410~~	~~3,287,612~~	~~11,972~~	~~67,277~~	~~603,640~~			

Table 4.2 (cont.): Current and Natural Conditions Baseline Nutrient and Organic Matter Loadings to the Klamath River in California

Klamath River TMDL Source Analysis Summary											
-		Annual Source Loads (lbs.)			Critical Period Source Loads (lbs.) May - October (six months)			Current Percent Total Annual Loading		
Source Area		TP	TN	CBOD	TP	TN	CBOD	TP	TN	CBOD
Shasta to Scott Tributaries ▪ Humbug Creek ▪ Beaver Creek ▪ Horse Creek	Current	6,302	35,414	317,758	1,673	9,401	84,348	0%	0%	0%
	Natural Baseline	6,302	35,414	317,758	1,673	9,401	84,348			
Scott River	Current	138,563	730,654	1,346,272	52,957	208,948	1,056,452	9%	9%	2%
	Natural Baseline	138,563	730,654	1,346,272	52,957	208,948	1,056,452			
Scott to Salmon Tributaries ▪ Grider Creek ▪ Thompson Creek ▪ Happy Camp Creek / Indian ▪ Elk Creek ▪ Clear Creek ▪ Ukonom Creek ▪ Dillon Creek	Current	68,217	383,328	3,439,406	12,978	72,930	654,360	4%	5%	5%
	Natural Baseline	68,217	383,328	3,439,406	12,978	72,930	654,360			
Salmon River	Current	70,302	577,951	6,726,394	15,358	192,412	1,946,043	4%	7%	10%
	Natural Baseline	70,302	577,951	6,726,394	15,358	192,412	1,946,043			
Salmon to Trinity Tributaries ▪ Camp Creek ▪ Red Cap Creek ▪ Bluff Creek	Current	32,713	183,829	1,649,404	6,002	33,726	302,610	2%	2%	3%
	Natural Baseline	32,713	183,829	1,649,404	6,002	33,726	302,610			
Trinity River	Current	302,196	2,274,814	26,532,671	56,891	460,714	4,780,372	19%	28%	41%
	Natural Baseline	360,625	2,719,956	31,627,566	75,449	610,999	6,339,738			
Trinity River to Turwar Tributaries ▪ Pine Creek ▪ Tectah Creek ▪ Blue Creek	Current	65,205	366,410	3,287,612	11,972	67,277	603,640	4%	4%	5%
	Natural Baseline	65,205	366,410	3,287,612	11,972	67,277	603,640			
Total of CA source areas	Current	1,612,295	8,267,604	64,778,312				100%	100%	100%

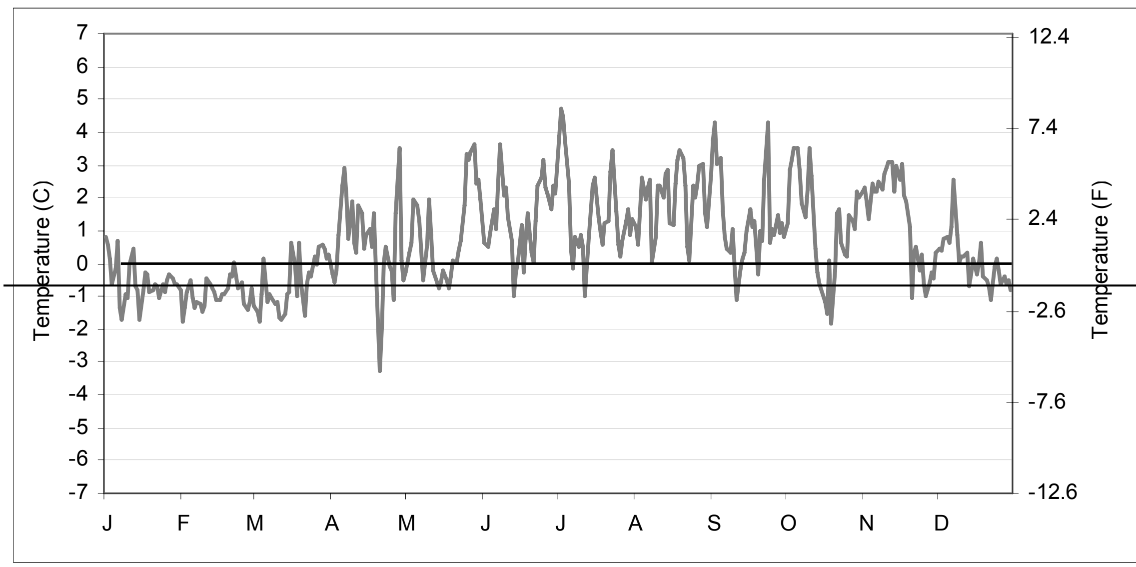
4.2 Pollutant Source Area Loads

This section discusses the pollutant loads from the key source areas.

4.2.1 Stateline – Upper Klamath Basin

4.2.1.1 Temperature

The combined water temperature effects of sources of increased thermal loads in Oregon were evaluated by comparing the results of the current condition model scenario (i.e. the calibrated model for 2000) with the natural conditions baseline scenario at stateline. The results, summarized in Figure 4.4, indicate that the sum of all sources upstream of California leads to significant temperature increases, possibly as much as 6~~9~~ ^{o}F (3.3~~5~~ ^{o}C), from approximately April to December. Positive values represent an increase above the natural conditions baseline. The ~~combined~~ sources represented in the current conditions scenario include alterations due to discharge of irrigation return flows (Klamath Straits Drain, Lost River Diversion Channel) and changes in hydrodynamics resulting from reservoir operations (Keno, JC Boyle).



~~Figure 4.4: Estimated temperature changes at Stateline due to reservoirs and irrigation return flows upstream. Positive values represent an increase above the natural conditions baseline.~~

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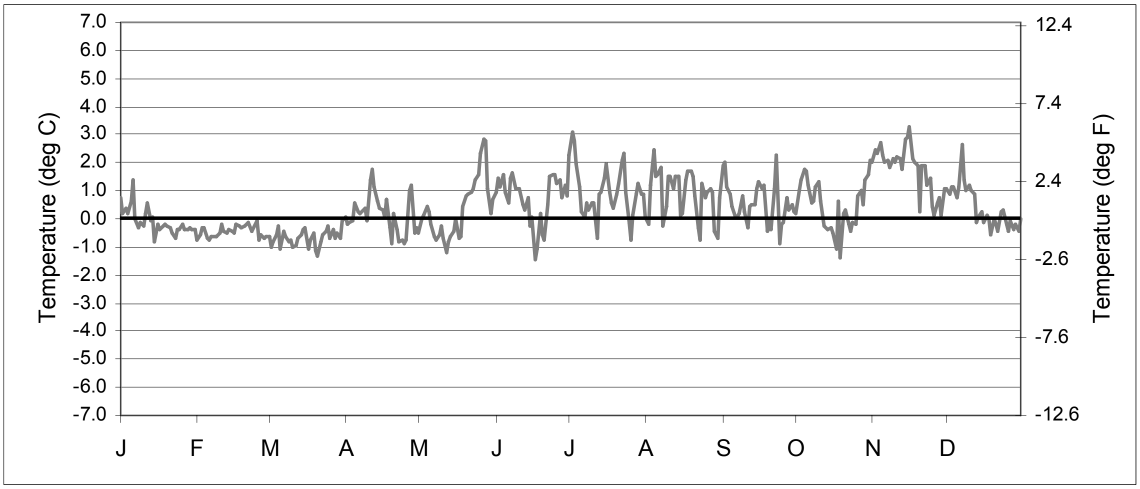

Figure 4.4: Estimated changes of daily maximum temperatures at Stateline due to ~~reservoirs and irrigation return flows~~anthropogenic sources upstream. Positive values represent an increase above the natural conditions baseline.

The diversion of water directly from the Klamath River and its tributaries, including Upper Klamath Lake, greatly alters the flow of the Klamath River, particularly in the spring. Reductions in flow can lead to increased diurnal temperature fluctuations, as well as increased daily average temperatures. These concepts are detailed in Section 2.4.3.3.

As described in ~~Section 3.3.2~~Appendix 7, the natural conditions baseline scenario was developed using current flows from Upper Klamath Lake and the Klamath Project area, and therefore does not reflect thermal impacts caused by ~~irrigation diversions~~reduced flows. Thus, Figure 4.4 also does not reflect those thermal effects. To assess the effects of altered flows due to diversions on water temperatures, model scenarios for current ~~conditions~~ flows and natural flows, with all other factors assigned as natural conditions, were compared. Figure 4.5 presents the difference in daily maximum temperature predicted to occur at stateline solely from differences in flow due to diversion of water (i.e. no dam effects and no irrigation return flow effects are represented in Figure 4.5). Positive values represent an increase in temperatures due to reduced flow. The temperature difference between the two scenarios is generally slight, but indicates as much as 2.7 ^{o}F (1.5 ^{o}C) increase in daily maximum temperature in early spring, a 3.6 ^{o}F (2.0 ^{o}C) decrease in May, and a 1.8 ^{o}F (1.0 ^{o}C) increase in November. The results illustrate the effects of the altered annual hydrograph presented in Figure 1.11, in which the unimpaired flows are higher in the Spring and lower in the Fall. This relatively ~~minimal~~ small difference in stream temperatures at stateline during the summer months is likely due to the fact that the source of the Klamath River, Upper Klamath Lake, is a relatively warm waterbody, reaching equilibrium temperatures irrespective of alteration in flow conditions during the summer season.

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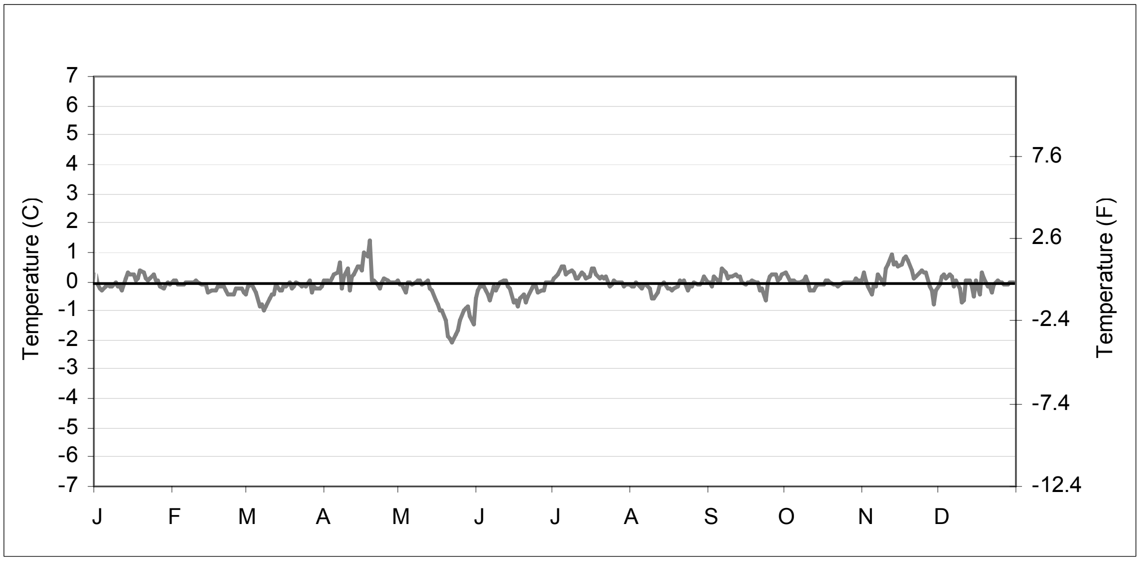
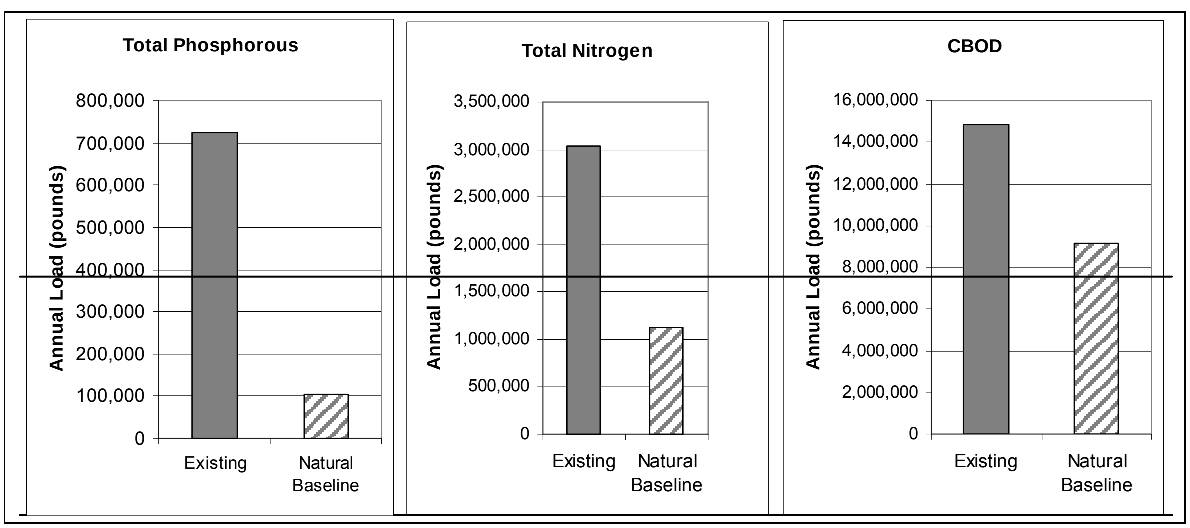


Figure 4.5: Estimated change in daily maximum temperature at Stateline resulting from altered flows, 2000 simulation year. Positive values represent an increase in temperatures due to reduced flow.

4.2.1.2 Nutrients and Organic Matter

The largest single source area for nutrient and organic matter loads to the Klamath River originates in the Upper Klamath basin above stateline. Current TP and TN loads at stateline comprise approximately 44~~5~~% and 3~~6~~7% of the TP and TN loading, respectively, to the Klamath River in California (Table 4.2). The above-Stateline fraction of the total organic matter (CBOD) loading to the California ~~A~~ portion of the Klamath River for CBOD is somewhat less at 27~~3~~%.~~The fraction for CBOD is somewhat less at 23%~~. Figure 4.6 compares the current annual TP, TN, and CBOD loads at stateline to those estimated loads under the natural conditions baseline, reflecting ~~585~~727%, ~~169~~248%, and ~~62~~169% increases in annual loads from natural conditions baseline for TP, TN, and CBOD, respectively.



~~Figure 4.6: Comparison of Current Annual TP, TN, and CBOD Loads at Stateline to Natural~~

~~Conditions Baseline Loads.~~

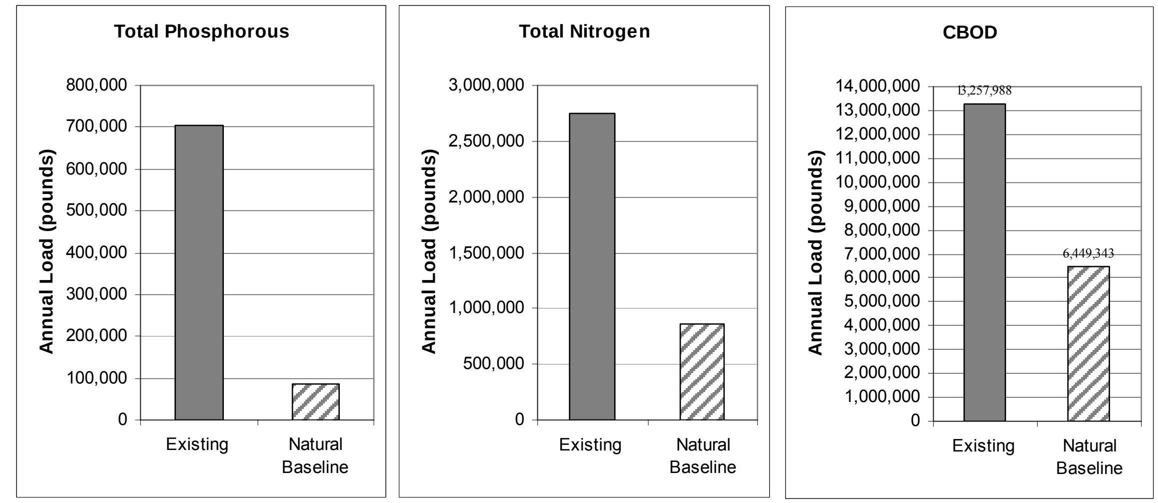


Figure 4.6: Comparison of Current Annual TP, TN, and CBOD Loads at Stateline to Natural Conditions Baseline Loads.

All of the land use source categories identified in Section 4.1.1 contribute to the increased loads at stateline. The Upper Klamath Lake Drainage TMDL (ODEQ 2002) analyzes the sources contributing loads to Upper Klamath Lake. In addition to irrigated agriculture, upland sources (e.g., gravel road surface erosion, timber harvest operations), nutrient flux from reclaimed wetlands, and internal nutrient loading from Upper Klamath Lake bottom sediments contribute to loading to Upper Klamath Lake. The movement of water from Upper Klamath Lake is regulated, with much of the flow diverted from the Klamath River into the Lost River basin to support irrigated agriculture, with some portion of these flows eventually transferred back to the Klamath River. Working in collaboration with ODEQ, Regional Water Board staff has developed the following source analysis of how the flows diverted to the Lost River basin impact water quality upon their return discharge into the Klamath River.

The Lost River Diversion Channel (LRDC) and Klamath Straits Drain (KSD) are part of United States Bureau of Reclamation's (USBR's) Klamath Project and discharge into the Klamath River in the impounded reach upstream of Keno Dam. These facilities, along with water withdrawal canals, hydrologically connect the Klamath River to the Link River system (for this document the "Lost River system" refers to the hydrologically connected natural and constructed portions of the Lost River, Tule Lake, Lower Klamath Lake, Klamath Straits Drain and other associated canals and drains). ODEQ is also developing a TMDL to address water quality impairments within the Lost River system in Oregon and EPA has promulgated a TMDL for the lower Lost River drainage in California (USEPA 2008). ODEQ'a Klamath River TMDL investigates the impact of discharge from LRDC and KSD to the Klamath River while the Lost River system TMDL investigates water quality impacts on the Lost River drainage .

USBR's Klamath Project supplies water to approximately 240,000 acres of cropland (38% of it in California and 62% of it in Oregon) (USBR 2009). Prior to the development of the Klamath Project, there was no surface water connection between the Klamath River and the Lost River system except during extreme flows (NRC 2004). With the advent of the Klamath Project, water is supplied from Upper Klamath Lake and Klamath River along with reservoirs and tributaries within the Lost River system. Included in the project are reclaimed lands of Tule Lake and Lower Klamath Lakes and facilities related to flood control. In terms of its relationship with the Klamath River, the Klamath Project withdrawals water from Upper Klamath Lake via A-canal and the impounded reach of the Klamath River behind Keno Dam via Ady Canal and North Canal. The LRDC can transfer water to or from the Klamath River. Pump stations at the western end of KSD transfer water to the Klamath River.

A number of studies have concluded that the USBR's Klamath Project is an annual net sink of nutrients in relation to the Klamath River (Rybost and Charlton 2001, Danosky and Kaffka 2002 and Hicks 2009). ODEQ extended the Hicks 2009 analysis to include an entire year, 2002, using DEQ data to supplement the USBR dataset. Daily flow estimates were obtained from USBR's website. When concentration data were not available for a specific canal, a nearby river concentration was used as a surrogate. For this analysis, sources of nutrients to the Klamath River are Klamath Straits Drain and Lost River Diversion Channel and extractions from the Klamath River are A-canal, Lost River Diversion Channel, North Canal and Ady Canal.

Even when examining an entire year of 2002, the Klamath Project appears to be a sink of nutrients in relation to the Klamath River (Figure 4.7). Despite the higher phosphorus concentrations returning to the Klamath River than leaving it, the loading is strongly influenced by the flow and only 30% of the flow that enters the Lost River system from the Klamath is returned to the Klamath River. In 2002, total phosphorus removed from the Klamath River was 2.8×10^5 pounds (130 metric tons) while 1.4×10^5 pounds (64 metric tons) was returned, equivalent to a 50% decrease in estimated total annual load. Total nitrogen removed from the Klamath River was 2.8×10^6 pounds (1300 metric tons) while 9.6×10^5 pounds (440 metric tons), equivalent to a 66% decrease in estimated total annual load.

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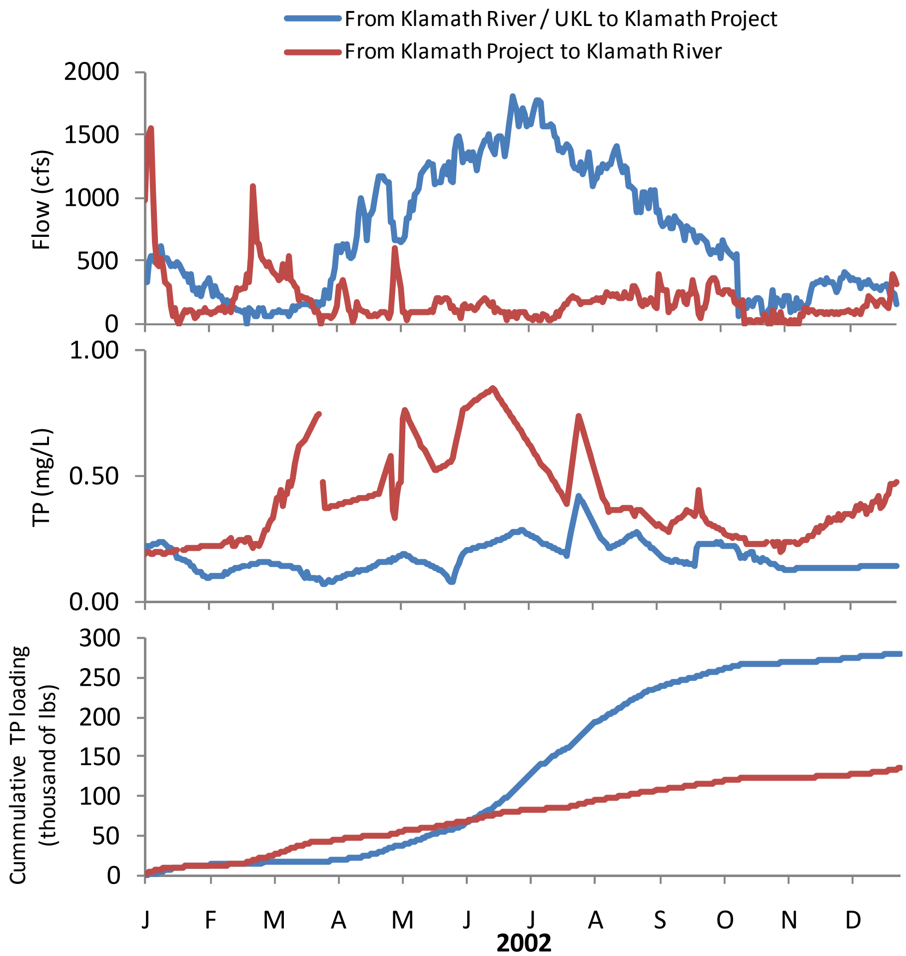

Figure 4.7: Flow, concentration and cumulative loading analysis of USBR's Klamath Project. Total phosphorus (TP) concentrations weighted based on relative flow rates.

Even though USBR's Klamath Project appears to be a net sink of nutrients, it also appears to have detrimental impacts to the water quality of Klamath River. Based on mean August 2002 flows, approximately 1255 cfs was diverted out of the Upper Klamath Lake and the Klamath River, leaving approximately 182 cfs in Keno Reservoir just upstream of Klamath Straits Drain (Figure 4.8). Klamath Straits Drain discharge then accounts for approximately half the flow of the Klamath River at Keno Dam. Therefore, its higher concentration of nutrients relative to the Klamath River increases the nutrient concentration which in turn contributes to water quality degradation in the Keno impoundment (Figure 4.9).

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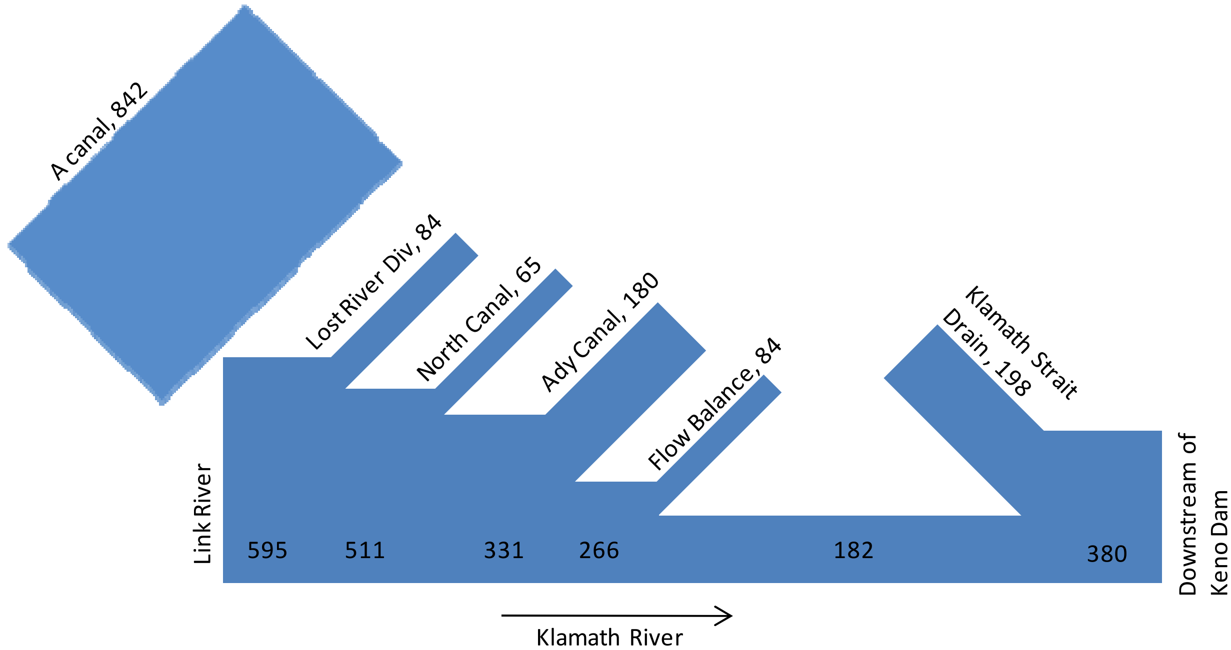

Figure 4.8: Schematic of an example flow balance in cubic feet per second for Keno Reservoir in August 2002. Flows are represented by the thickness of each box. The flow balance portion was derived by subtracting the outflow from the other measured flows.

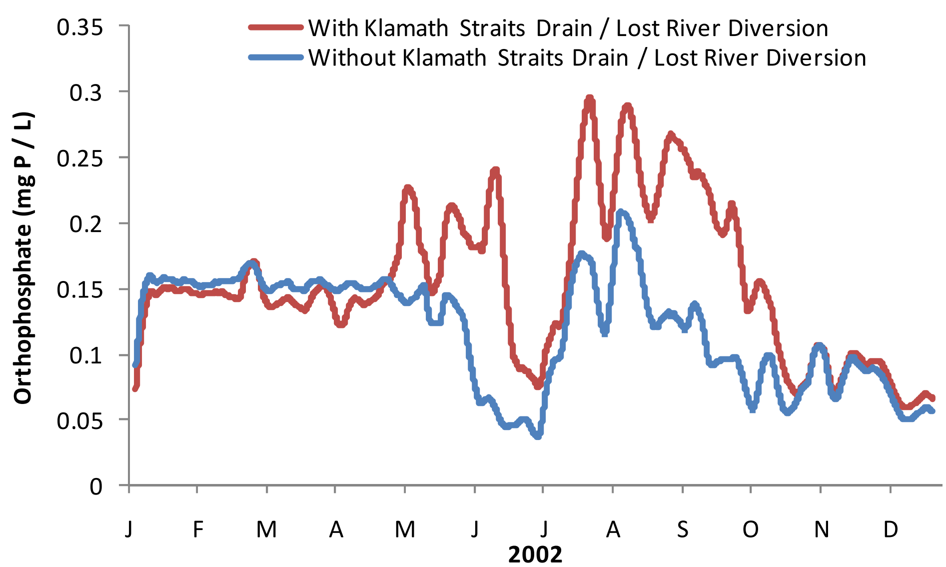

Figure 4.9:. Klamath River (Keno Reservoir) model results from just downstream of Klamath Straits Drain discharge. The “With Klamath Straits Drain / Lost River Diversion” results are from the 2002 calibration model. The “Without …” results are from a scenario exactly like the 2002 calibration except the constituent concentrations of parameters for Lost River Diversion and Klamath Straits Drain were set to the same constituent concentrations as Link River.

The following information is also provided regarding the potential for agricultural operations within the Lost River drainage to affect nutrient dynamics and thus impact water quality within the Klamath basin.

A water quality study in the Tule Lake irrigation district by the University of California Davis concluded: “The differences in water quality between tiles and drainage ditches suggest that the ditches and water management infrastructure itself has a role in regulating nutrient transfers and can contribute nutrients (especially TP) to the system: from internal hydrologic cycles present in the ditches and canals, from agitation of sediments, from the death and decay of aquatic plants, from N fixation by blue green algae, and from N fixation of sediments due to pumping and transfer of water” (Danosky and Kaffka 2002).

These results are consistent with a water quality investigation by USGS in the Yakima basin (McCarthy and Johnson, 2009). The water quality investigation indicated that combining irrigation and artificial-drainage networks may exacerbate the ecological effects of agricultural runoff by increasing direct connectivity between fields and streams and minimizing potentially mitigating effects of longer subsurface pathways such as denitrification and dilution. Similar findings relative to Upper Klamath Lake are reported by Rykbost and Charlton (2001):

> "Nutrient loading in Klamath Lake is unquestionably enhanced by the drainage of irrigation water from agricultural properties adjacent to the lake. Prior to reclamation, all of these properties were either permanent or seasonal wetlands. Following construction of dikes and drainage systems, the properties were managed for pastures and/or crop production. Soils are high in organic matter content and native fertility; therefore pastures and hay crops on these lands are generally not fertilized. Natural processes associated with mineralization of these soils release nutrients subject to transport in drainage water."

~~While current condition mass loading estimates indicate that the Klamath Project area provides some seasonal net nutrient load reductions when comparing input and output waters to and from the Klamath Project area, compared to natural conditions baseline, current practices within the Klamath Project area contribute loading to the Klamath River at Klamath Straits Drain and intermittently at the Lost River Diversion Channel. Those sources within the California portion of the Lost River are analyzed in the Lost River, California TMDL (USEPA 2008). Those sources within the Oregon portion of the Lost River are analyzed as part of ODEQ’s Lost River TMDL. Finally,~~ There are also municipal and industrial point sources discharge to the Klamath River within Oregon. There are two municipal wastewater point sources that discharge to the Klamath River in Oregon: South Suburban Sanitation District and Spring Street Sanitation plant run by the City of Klamath Falls. There are two industrial wastewater point sources that discharge to the Klamath River in Oregon: Columbia Forest Products, and Collins Forest Products. There is one municipal wastewater point source~~s~~ that discharges to the Lost River system, the City of Tulelake wastewater treatment plant.

All of these pollutant sources and loads have been considered in the Stateline pollutant source analysis (Figure 4.6).

4.2.2 Copco 1 and 2 and Iron Gate Reservoirs

4.2.2.1 Temperature

An analysis of model results was prepared that isolates the effects of each reservoir (Copco 1 and 2 and Iron Gate), in order to evaluate the impacts of the reservoirs on Klamath River temperature. The effects of the reservoirs were isolated by calculating the change in river temperature between the upstream and downstream limits of each reservoir for both current and natural conditions baseline. The temperature impact of each reservoir was calculated by subtracting the change in temperature that would result from free-flowing conditions (i.e. in the absence of the reservoirs) in the reservoir reaches from the change in temperature that currently occurs in the reservoir reaches. The resulting calculation estimates the change in temperature due to the presence of the reservoirs, by subtracting the amount of heating expected to occur in a natural (free-flowing) state.

The results of the modeling analysis demonstrate that the presence of Copco 1 and 2 significantly influences the temperature of the Klamath River in that reach. Figure 4.~~7~~ 10 presents the change in daily maximum temperature associated with the presence of the reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Copco 1 and 2. These results indicate that the presence of Copco Reservoir can increase Klamath River water temperatures by ~~more than~~ as much as 6.8~~5.4~~ °F (3.8~~0~~ °C) during the late summer and fall months, and can decrease daily maximum temperatures by ~~nearly~~ up to 13.~~2~~3 °F (7.4 °C).

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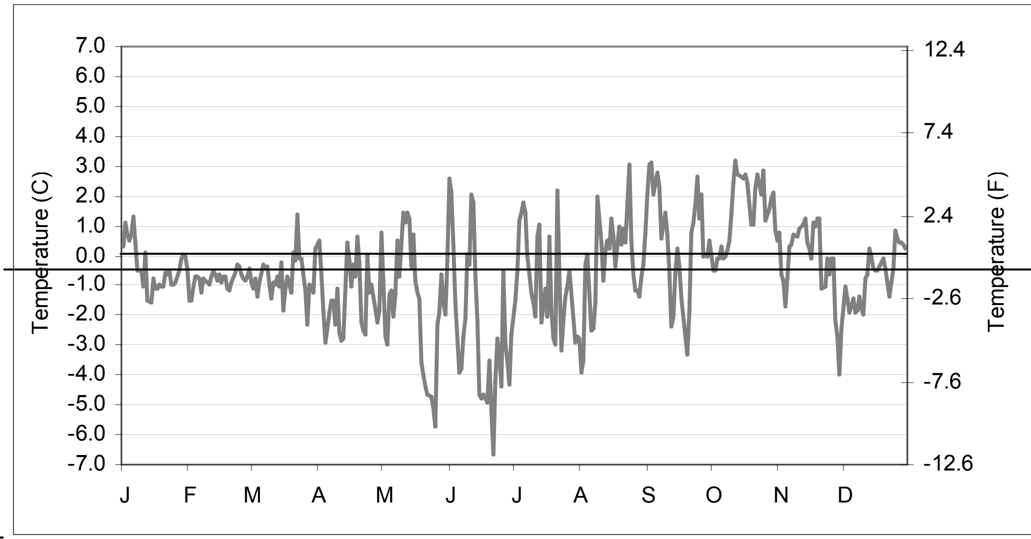


~~Figure 4.7: Calculated change in daily maximum Klamath River temperatures resulting from the presence of Copco Reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Copco 1 and 2.~~

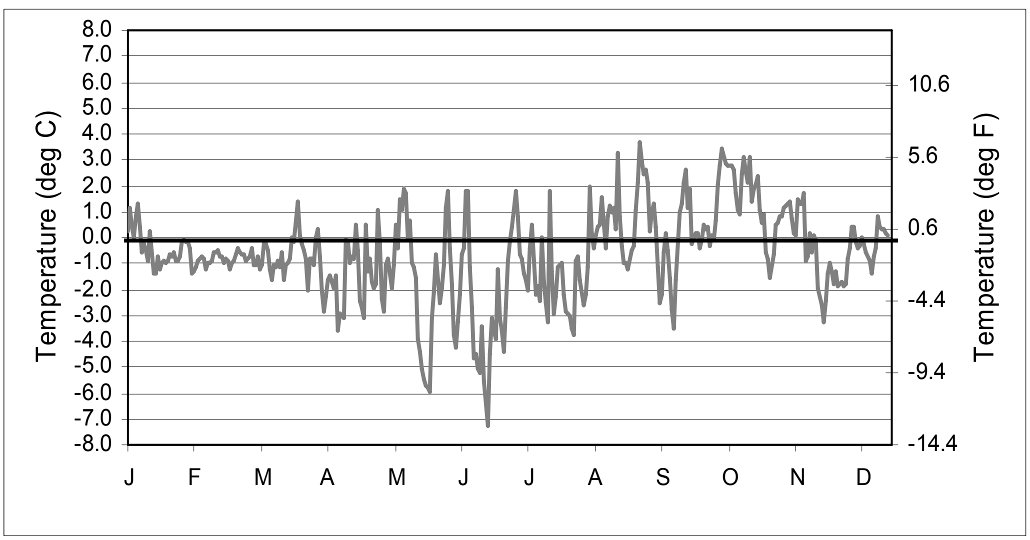
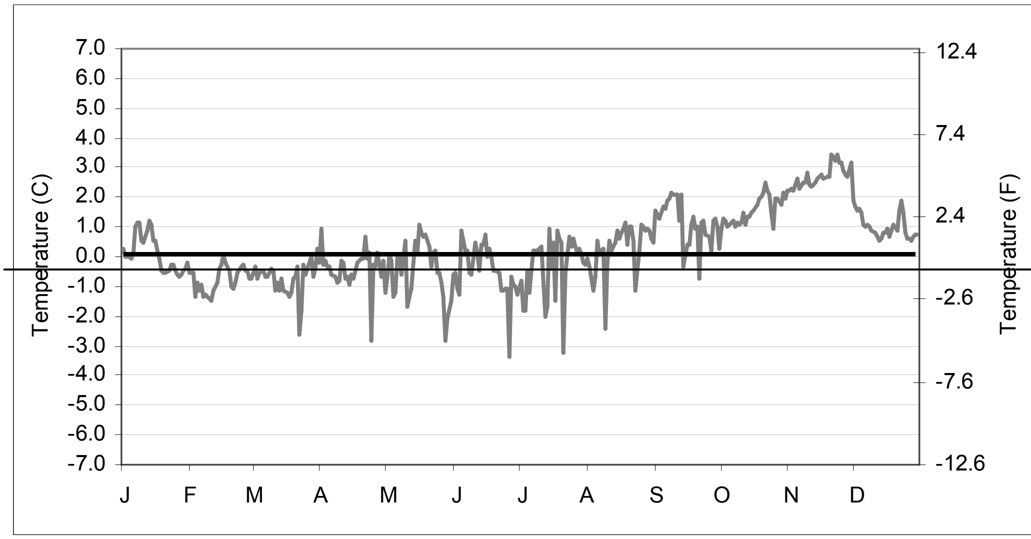


Figure 4.~~7~~10: Calculated change in daily maximum Klamath River temperatures resulting from the presence of Copco Reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Copco 1 and 2.

The results of the Iron Gate modeling analysis are very similar to the Copco analysis results. The results also demonstrate that the presence of Iron Gate Reservoir significantly influences the temperature of the Klamath River in that reach. Figure 4.~~8~~ 11 presents the change in daily maximum temperature associated with the presence of the reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Iron Gate Reservoir. These results indicate that the presence of Iron Gate Reservoir increases Klamath River daily maximum water temperatures by up to 5.8~~6.3~~ ^{o}F (3.2~~5~~ ^{o}C) during the fall months. The timing of this increase coincides with the time when Chinook salmon currently spawn in the Klamath River mainstem directly downstream of the reservoir. The results also indicate that Klamath River daily maximum water temperatures decrease by a similar magnitude (up to 6.8~~3~~ ^{o}F [3.8~~5~~ ^{o}C]) for short periods throughout the year, and that the presence of Iron Gate reservoir generally results in reduced daily maximum temperatures by approximately 1.8 ^{o}F (1.0 ^{o}C) from ~~the~~ February to August.



~~Figure 4.8: Calculated change in daily maximum Klamath River temperatures resulting from the presence of Iron Gate Reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Iron Gate Reservoir.~~

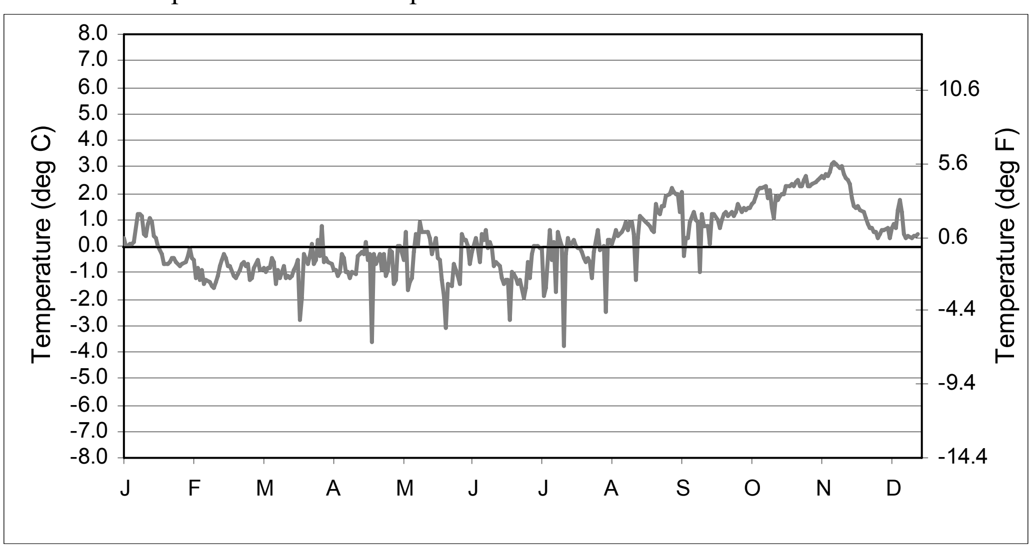


Figure 4.~~8~~11: Calculated change in daily maximum Klamath River temperatures resulting from the presence of Iron Gate Reservoir for the 2000 calendar year. Positive values represent an increase in temperatures due to the presence of Iron Gate Reservoir.

The analyses of the effects of Iron Gate and Copco 1 and 2 Reservoirs indicate that each of these reservoirs can increase Klamath River water temperatures in these reaches by ~~as~~

~~much~~ more than as 5.0~~6.3~~ °F (2.8~~3.5~~ °C). ~~However, in reality the effects of the reservoirs are not additive and do not necessarily result in a total increase of up to 12.6 °F (7.0 °C). This is because Copco Reservoir heats the water to a level close to the equilibrium temperature, so the water is close to equilibrium when entering Iron Gate Reservoir. The rate of heating is proportional to the difference between the instantaneous temperature and the equilibrium temperature. This concept is taken into account and addressed in the temperature load allocation and implementation recommendations for these facilities.~~Such an increase is explicitly prohibited by the intrastate water quality objective for temperature, which limits temperature increases at any time or place to 5.0 °F (2.8 °C).

4.2.2.2 Dissolved Oxygen, Nutrients, Organic Matter, Chlorophyll-a, *Microcystis aeruginosa* and Microcystin

The purpose of this section is to describe the complex manner in which increased residence time and heat gain (found in the reservoirs)~~reservoirs~~ affect the dynamics of the Klamath River and ~~how reservoirs~~ ultimately impact dissolved oxygen, nutrients, organic matter, chlorophyll-a, *Microcystis aeruginosa* and microcystin. The reservoir related impacts require that reservoirs be considered as a contributing source area and assigned allocations and numeric targets as part of this TMDL.

Dissolved Oxygen

As discussed in Chapter 2 and illustrated in Figure 2.15, ~~the presence of~~within Copco 1 and 2 and Iron Gate Reservoirs ~~creates~~ DO conditions exist that do not meet water quality standards. Iron Gate and Copco Reservoirs become stratified during the summer months with warm, DO-rich water near the surface and colder, DO-poor water near the bottom. For much of the summer season, there is no overlapping layer that has DO and temperature conditions where both are simultaneously supportive of the COLD beneficial use. For this assessment, DO concentrations less than 6 mg/L are used as a screening-level target for assessing suitability of DO for COLD. In Iron Gate Reservoir, the levels of DO are only suitable for resident rainbow trout to a depth of 4 meters, on average (rainbow trout are assumed to be the most sensitive cold water-dependent species currently present in the California reservoirs). However, surface water temperatures in Iron Gate reservoir exceed the natural summer mean (18.7 ° C under free-flowing conditions) and frequently reaches levels that are stressful ~~in Iron Gate Reservoir are not low enough to fully support~~which results in non-supporting conditions for resident rainbow trout above a depth of approximately 10 meters. Copco Reservoir similarly stratifies, with suitable DO above approximately 7.5 meters depth and suitable temperatures below 17 meters deep. Monitoring data demonstrating these conditions, which persist throughout the stratified portions of the reservoirs for much of the summer period, have been reported on several occasions, including the PacifiCorp Water Quality Conditions reports for 2007 and 2008 (PacifiCorp 2007 - , PacifiCorp 2008 – Figures 3-14 and 3-16; and PacifiCorp 2009 – Figures 23 and 24). By contrast, under free-flowing river and natural temperature conditions, there would be co-occurring temperature and DO conditions that meet ~~standards~~these targets.

The occurrence of DO conditions that do not ~~meet standards~~provide supporting conditions within Copco 1 and 2 and Iron Gate Reservoirs during summer months is due to the physical characteristics of these reservoirs and the nutrient and organic matter loads entering the reservoirs, and is exacerbated by internal nutrient and organic matter loading within the reservoirs.

Changed Environment, Internal Nutrient Cycling, and Biostimulatory Conditions

Reservoirs alter the nutrient dynamics of a river system. By design, reservoirs represent areas of a river system in which velocity is decreased and residence time increased. The discussion of residence time for Copco and Iron Gate Reservoirs below comes from estimates developed by Tetra Tech (2008) as part of an evaluation of nutrient retention by Copco and Iron Gate Reservoirs:

> For the two downstream reservoirs in the Klamath system, Copco and Iron Gate, the relevant parameters are given in Table 4.3. Determination of a residence time is problematic for run-of-river reservoirs that are dominated by winter flow-through. Not only does residence time vary throughout the year, but in addition the reservoirs are not well-mixed in summer, and retention time in the hypolimnion may be much longer than in the epilimnion. For the period of May 2005 through May 2006 reported by Kann and Asarian (2007), the overall residence time in both reservoirs was on the order of 6 days, but the summer residence time of surface waters was around 20-25 days for Copco and 25-35 days for Iron Gate (but can reach as high as 50 days in Iron Gate).

Table 4.3 Hydraulic Parameters for Klamath Reservoirs (May 2004 – May 2005)

Impoundment	Residence Time (*T*, yrs)	Mean Depth (*z*, m)
Copco	0.0384	11.7
Iron Gate	0.0484	16.6

The relatively quiescent waters in Copco and Iron Gate Reservoirs promote the settling of particulate material, including nutrient-bearing organic material and algae, and nutrients (i.e. PO_4 and NH_4) sorbed to inorganic sediment. In addition, the physical characteristics of these reservoirs cause them to stratify during summer months, resulting in the bottom layer of the reservoir (i.e. hypolimnion) becoming devoid of oxygen (i.e. anoxic). Under these conditions, organic debris (including dead algal detritus) that has settled to the bottom of the reservoir is subject to one or more of the following processes that can lead to the transfer of nutrients from the reservoir bottom sediments back into the water column; processes collectively referred to as internal nutrient loading:

- If the sediments are disturbed by wind-driven currents or by other means (organisms or degassing) interstitial nutrients can be transferred to the water column simply by agitation.
- Decrease in the redox potential (increase in the availability of electrons) in the surficial bottom sediments caused by intensive microbial respiration, as would be the case for highly organic sediment, can cause biogeochemical changes that result in accelerated release of mineralized or soluble organic phosphorus and

ammonia from the sediments to the overlying water, even if the sediments are immobile.

- High pH at the sediment surface may cause release of adsorbed phosphorus from sediments, with or without agitation of sediments.
- In stratified lakes suspended algae cells may, under calm conditions, sink to deeper waters at or below the thermocline, where phosphorus is more concentrated than in the surface waters where most photosynthesis occurs, and then be re-suspended either by wind or buoyancy control mechanisms after assimilating phosphorus, thus bringing phosphorus from the sediments to the water column. This phenomenon has been documented by Moisander (2008) and illustrated in Figure 4.13.
- ~~In addition to the physical processes described above~~R ~~r~~eservoirs ~~can also develop~~having large populations of nitrogen fixing algae and blue-green algae ~~which~~ can significantly contribute to nitrogen concentrations in~~to~~ the water column ~~and~~ for export~~ed~~ downstream.

These internal nutrient loading processes can occur simultaneously within a reservoir, and serve as an input (or source) of nutrients into the water column of the reservoir. In ~~turn~~addition, phosphate (PO_4) and ammonia (NH_4), the dissolved inorganic nutrients that were once sequestered within the sediments, become available for uptake by planktonic algae within the reservoir, or can move out of the reservoir and be available for uptake by attached algae (i.e. periphyton) in downstream river reaches. This export of dissolved inorganic nutrients from the reservoir to the river ~~can occur~~is a concern when occurring within the window of the critical growth period for periphyton within the river.

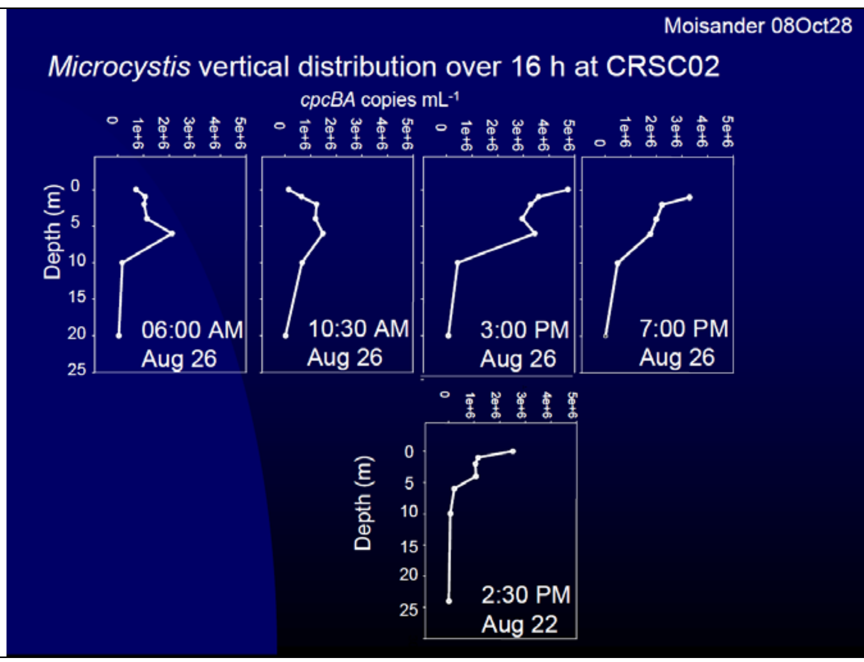
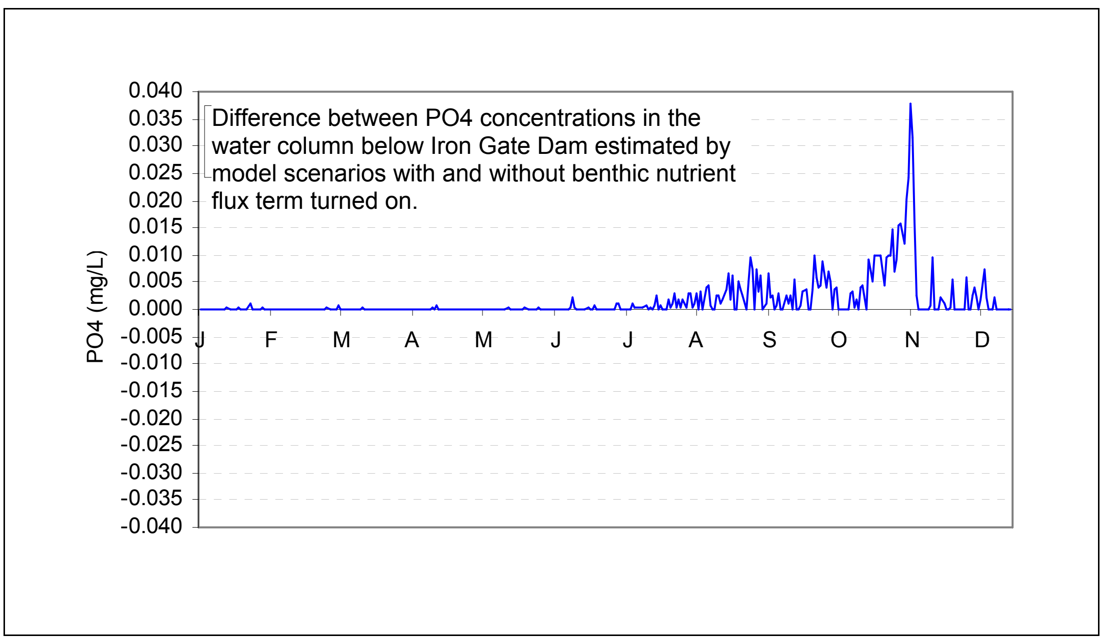


Figure 4.13: Vertical migration of *Microcystis* over a 16 hour period in Copco Reservoir on August 26, 2006. (Moisander (2008))

~~In order to isolate the change in nutrient loads from Copco 1 and 2 and Iron Gate attributed to the release of nutrients from the bottom sediments under anoxic conditions, a~~

~~modeled sensitivity analysis was run. The Klamath River TMDL model includes a benthic flux term that simulates the release of nutrients from sediments at the bottom of the reservoir under anoxic conditions. When the benthic flux term is turned *off* for both reservoirs within the model, no nutrients are released from the bottom sediments, even when anoxic conditions in the hypolimnion are simulated in the model. A comparison of resulting nutrient concentrations at the outlet tailrace of Iron Gate under two scenarios (with the benthic flux term turned on and off for both reservoirs) indicates the estimated relative contribution to nutrient concentrations (and loads) resulting from the release of nutrients from bottom sediments under stratified anoxic conditions.~~

~~The results of this comparison at Iron Gate Dam for inorganic phosphate (PO_4) are illustrated in Figure 4.93, and indicate the potential for increased downstream PO_4 concentrations beginning in early June (beginning of summer stratification) and tapering off in late November (post turnover, no stratification). Based on the results of this sensitivity analysis, any peak above the mid-line (0.000) accounts for increased concentrations of PO_4 being released through the reservoir outlet downstream during stratified anoxic conditions. This increase in bio-available phosphorus occurs during the critical growth period, contributing to biostimulatory conditions downstream of the reservoirs.~~



~~Figure 4.93: Comparison of PO_4 concentrations immediately downstream of Iron Gate Reservoir illustrating contribution of nutrient flux from reservoir sediments under anoxic conditions (summer stratification).~~

~~Results of this benthic flux sensitivity analysis are also used to quantify the annual nutrient loading to Copco 1 and 2 and Iron Gate attributed to nutrient release from bottom sediments. Annual and critical summer season bottom sediment TP and TN loads for both Copco and Iron Gate are presented in Table 4.2. A comparison of the current annual and critical season growth period bottom sediment nutrient flux loads for Copco 1 and 2 and Iron Gate Reservoirs demonstrates that the majority of these loads occur during the~~

~~summer months; the period when an increase in biostimulatory conditions exacerbates the water quality impairments in the Klamath River. Therefore, both the timing and form of this source load contributes to the water quality impairments.~~

~~While these bottom sediment nutrient flux loads are relatively small compared to the current total loadings entering the reservoirs, they do represent a controllable increase in nutrient loading that would not occur in the absence of anoxic conditions created by the presence of the reservoirs. The release of nutrients from the sediments during the critical growth period contributes to biostimulatory conditions both within the reservoir and immediately downstream of Iron Gate.~~

~~The quiescent conditions of the reservoirs also have a biostimulatory effect that contributes to an increased likelihood of nuisance blooms of suspended algae and toxic blue-green algal dominance. The evidence of this effect is detailed in Section 2.5.3.4, which demonstrates a clear response of phytoplankton to the environment created by Copco and Iron Gate Reservoirs.~~

Role of Copco and Iron Gate Reservoirs in Klamath River Nutrient Dynamics

The purpose of this section is to briefly review the impact of Copco and Iron Gate Reservoirs on Klamath River nutrient dynamics through an evaluation of various estimates of their nutrient retention / export characteristics. Nutrient loads delivered downstream of the reservoirs are influenced by retention and export from the reservoirs. Retention and export can vary annually and seasonally ~~potentially~~ causing the reservoirs to alternate between being either sources or sinks. A recently completed 30-month study of reservoir nutrient budget dynamics (Asarian et al. 2009) provides a strong empirical foundation for this assessment.

For the purposes of this report the term retention is meant as *net* retention, which is the difference between influent and effluent loads. The net retention includes both permanent losses to the atmosphere and deep burial along with temporary storage and exchanges with the active sediment and gains from the atmosphere due to nitrogen fixation. However, only the net effect of these processes can be resolved and validated from observed water column concentration data. Ultimately, it is the net retention – the difference in loads and the resulting differences in concentration – that controls eutrophication response in the reservoirs and export of nutrients downstream. Table 4.4 presents the current annual and critical summer growth period (May – October) TP and TN loadings at stateline, Copco 2 outlet, and Iron Gate outlet based on the calibrated TMDL model results for 2000.

~~Table 4.4 TMDL Model Estimates of Current Total Phosphorus and Total Nitrogen Loads at Stateline, Copco Outlet, and Iron Gate Outlet~~

~~Current Conditions~~	~~Annual Source Loads (lbs.)~~		~~Critical Period Source Loads (lbs.) May - October~~	
~~Source Area~~	~~TP~~	~~TN~~	~~TP~~	~~TN~~
~~Klamath River – Stateline~~	~~722,659~~	~~3,040,279~~	~~325,171~~	~~1,393,022~~
~~Copco Reservoirs – tailrace~~	~~702,113~~	~~2,674,647~~	~~320,776~~	~~1,106,286~~
~~Iron Gate Reservoir – tailrace~~	~~735,129~~	~~2,810,655~~	~~325,308~~	~~980,102~~

Table 4.4 TMDL Model Estimates of Current Total Phosphorus and Total Nitrogen Loads at Stateline, Copco Outlet, and Iron Gate Outlet

Current Conditions	**Annual Source Loads (lbs.)**		**Critical Period Source Loads (lbs.) May - October**	
Source Area	**TP**	**TN**	**TP**	**TN**
Klamath River - Stateline	717,523	3,020,913	316,898	1,348,967
Copco Reservoirs – tailrace	703,047	2,752,359	315,260	1,109,887
Iron Gate Reservoir – tailrace	772,016	2,891,510	341,109	1,003,978

Table 4.5 presents a summary of analyses regarding nutrient retention and export for Copco and Iron Gate reservoirs. The analyses include model estimates as well as empirical data analysis. As an example, the TMDL model estimates in the first row of each section (TP or TN) of Table 4.5 shows the percentage change in loading for TN and TP from stateline to Copco and from stateline to Iron Gate. A positive percentage change represents net retention and a negative percentage change represents net export. Within the critical summer growth period (May – October), the TMDL model estimates ~~there is minimal change in~~a combined reservoir retention of TP ~~loads~~ of 7.6% annually and 6.0% during the period May to October. For nitrogen the annual retention is 14.9% and 30% during the summer growing period (May to October). ~~within these reaches, but approximately 30% retention of TN from Iron Gate. The ~30% export retention is likely a high estimate because the TMDL model retention does not account for the nitrogen exported downstream within living algal biomass from algae growing within the reservoir and taking up nitrogen from the water column.~~ The TMDL model estimates are ~~reasonably~~ consistent with the estimates developed by Asarian and Kann (2009) through statistical analysis of empirical monitoring data. Asarian and Kann have estimated the combined effect ~~(not presented in Table 4.5)~~ of the reservoirs to be ~~13.0~~15% retention of TN and ~~8.3~~10% retention for TP on an annual basis and seasonally TP 8% and TN 31%. ~~The Asarian and Kann assessment of the combined seasonal effect for total phosphorous is consistent with the TMDL model estimate with a 1% export of total phosphorous during the May to December period.~~

The other estimates included in Table 4.5 were taken from an analysis of nutrient dynamics in the Klamath River performed by Tetra Tech (2008) and included as Appendix 3 to this report. Some of these estimates have somewhat greater variance, but overall, the analyses demonstrate that the reservoirs retain total nutrients on an annual basis, with the exception that some of the analyses indicate that the reservoirs have the potential to export a small amount of ~~total phosphorus~~TP.

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~~Table 4.5 Estimated Nutrient Retention and Export for Copco and Iron Gate Reservoirs~~

-	~~Time Period Assessed~~	~~Method~~	~~Copco~~	~~Iron Gate~~
~~Total Phosphorous~~	~~2000 - annual~~	~~TMDL Models~~	~~1%~~	~~-1%~~
	~~2000 - May to October~~	~~TMDL Models~~	~~-1%~~	~~-1%~~
	~~2004 - 2005~~	~~Vollenweider (1976)~~	~~16.4%~~	~~17.3%~~
	~~2004 - 2005~~	~~Nürnberg (1984)~~	~~4.6%~~	~~3.8%~~
	~~2004 - 2005~~	~~Range of 5 methods cited by Kann and Asarian (2007)~~	~~1.4% - 29%~~	~~1.9% - 29%~~
	~~2005 - 2007 - entire study period~~	~~Asarian and Kann (2009)~~	~~4.1%~~	~~4.5%~~
	~~2005 - 2007 - May to Dec.~~	~~Asarian and Kann (2009)~~	~~-3.0%~~	~~2.0%~~
-	-	-	-	-
~~Total Nitrogen~~	~~2000 - annual~~	~~TMDL Models~~	~~5.0%~~	~~14.0%~~
	~~2000 - May to October *~~	~~TMDL Models~~	~~14.0%~~	~~33.0%~~
	~~2004-2005~~	~~Bachman (1980)~~	~~13.8%~~	~~14.5%~~
	~~2004-2005~~	~~Range of 2 methods cited by Kann and Asarian (2007)~~	~~8.7% - 10.3%~~	~~9.4% - 10.0%~~
	~~2005 - 2007 - entire study period~~	~~Asarian and Kann (2009)~~	~~6.9%~~	~~6.7%~~
	~~2005 - 2007 - May to Dec.~~	~~Asarian and Kann (2009)~~	~~6.0%~~	~~10.0%~~

~~**Notes:**~~
- ~~TMDL model estimates include river reach from stateline through reservoir tailracees.~~
- ~~Positive number is net retention; negative number is net export~~

Table 4.5 Estimated Nutrient Retention and Export for Copco and Iron Gate Reservoirs

-	Time Period Assessed	Method	Copco	Iron Gate	Combined
Total Phosphorous	2000 - annual	TMDL Models	5.1%	3.3%	7.6%
	2000 - May to October	TMDL Models	4.7%	2.0%	6.0%
	2004 - 2005	Vollenweider (1976)	16.4%	17.3%	-
	2004 - 2005	Nürnberg (1984)	4.6%	3.8%	-
	2004 - 2005	Range of 5 methods cited by Kann and Asarian (2007)	1.4% - 29%	-1.9% - 29%	-
	2005 - 2007 - entire study period	Asarian et al. 2009			10.0%
	2005 - 2007 - May to September	Asarian et al. 2009			8.0%
-	-	-	-	-	-
Total Nitrogen	2000 - annual	TMDL Models	10.0%	6.7%	14.9%
	2000 - May to October*	TMDL Models	18.6%	16.0%	30.1%
	2002 – March to November	PacifiCorp (2006)			21%
	2004-2005	Bachman (1980)	13.8%	14.5%	-
	2004-2005	Range of 2 methods cited by Kann and Asarian (2007)	8.7% - 10.3%	9.4% - 10.0%	-
	2005 - 2007 - entire study period	Asarian et al. 2009			15.0%
	2005 - 2007 - May to September	Asarian et al. 2009			31.0%

Notes:
- TMDL model estimates include river reach from stateline through reservoir tailracees.
- Positive number is net retention; negative number is net export

Net retention is an important factor in assessing the affect of the reservoirs on nutrient dynamics, but there are several other factors that must also be considered to determine the comprehensive effect on water quality. Several of these factors were discussed previously (Section 2.4.2.1) when considering the impoundments as a risk cofactor for nutrient and organic matter related impacts on beneficial uses. A summary of these factors includes:

- The effect of retaining the nutrients within the reservoirs with respect to contributions to the nuisance algal conditions in the reservoirs.
- The net retention amounts are small relative to the nutrient-rich conditions downstream of Iron Gate Dam.
- It is clear that the reservoirs spread out event-driven spikes of nutrient loads. However, this is not necessarily a good thing in regard to algal response in the lower river. Without the impoundments, much of the nutrient load would move in event-driven pulses, and a good portion of such loads would flush through the system without elevating concentrations for long enough or at an appropriate time of year to promote elevated periphyton growth.
- For phosphorus, it is inappropriate to assess retention only at an annual time step, as the majority of the retention occurs in Winter-Spring, when more of the phosphorus is in particulate form and water quality conditions (i.e., flow, light, temperature) are not subject to biostimulatory conditions.

The reservoir source analysis provides several key findings for the development of the Klamath River TMDLs:

- Conditions within the reservoirs cause depletion of dissolved oxygen below levels needed for support of the fishery and will require dissolved oxygen allocations to ensure support of beneficial uses.
- The slow-moving waters of the reservoirs lead to enhanced algal growth. Biostimulatory conditions within the reservoirs are a result of excessive nutrient loads f~~o~~rom upstream and the environment created by the presence of the dams. Chlorophyll-a and blue-green algal related targets are achieved above the reservoirs but not within the reservoirs, thus the slower and warmer waters in the reservoir~~s~~ reaches~~ themselves~~ are the cause of these impairments.
- The nutrient retention and export lines of evidence in Table 4.5 suggest that the reservoirs provide some ~~limited~~ retention of nutrients. However,~~ and also affect the timing of nutrient delivery downstream. This retention plays an important but not dominant role in regulating and reducing the movement of nutrient loads to the downstream reaches. Because the net retention of nutrients is small, the nutrient loads transported past Iron Gate would be in excess of acceptable loads with or without the dams in place.~~ there are negative water quality affects associated with changes in nutrient dynamics, and the environment created by the reservoirs is a risk co-factor that contributes to water quality impairments both within the reservoirs and downstream.

The primary impact of the reservoirs as a source area (aside from temperature impacts already described) is their role in creating biostimulatory conditions leading to high levels of chlorophyll-a and blue-green algae (including microcystin), and the oxygen deficits found during the summer months.

4.2.3 Iron Gate Hatchery

The California Department of Fish and Game (CDFG) operates Iron Gate Hatchery, a salmonid fish hatchery and rearing facility immediately downstream from Iron Gate Dam. This facility is operated in accordance with an NPDES permit. Iron Gate Dam was constructed without volitional fish passage capabilities. Thus, the hatchery was constructed concurrently with Iron Gate Dam in 1962 to mitigate for migrating salmonid stocks that would no longer have access to spawning and rearing habitat upstream from Iron Gate Dam. Since the hatchery is part of the mitigation required of PacifiCorp due to the blockage by the dam of salmonid habitat upstream of the dam, PacifiCorp is a co-permittee with CDFG for the facility.

Water for hatchery operations is supplied from Iron Gate Reservoir. There are two intakes from the reservoir which deliver water to the fish hatchery: one at a depth of approximately 18 feet and the other at a depth of approximately 74 feet below normal pool elevation (actual depths vary depending on the water level in the reservoir). During the cooler months, water is withdrawn from 18 feet; as water temperatures in the reservoir warm, the intake point is moved to the lower depth (74 feet). Average flows through the hatchery system are estimated to be 16.1 million gallons per day (mgd) (24.9 cubic feet per second [cfs]), while maximum flows are 31.9 mgd (49.4 cfs). The hatchery consists of an aeration tower, adult holding ponds, a fish ladder, an adult trap, spawning facilities, a production pond system (~~,~~ where juvenile fish are reared), and two settling ponds. During daily operations, flows ranging from 7.75 to 15.5 mgd (12.0 to 24.0 cfs) pass through the production and settling ponds and discharge directly into the Klamath River. These flows carry waste generated during the feeding and care of the fish including suspended solids, settleable solids, and chemicals used in disease control. When the fish production ponds are cleaned, flows ranging from 1.9 mgd to 5.5 mgd (2.9 cfs to 8.5 cfs), comprised of metabolic wastes, unconsumed food, algae, silt, and detritus, are released to settling ponds, and then into the Klamath River.
~~Average flows through the hatchery system are 16.1 million gallons per day (mgd) (1494.6 cubic feet per second [cfs]), while maximum flows are 31.9 mgd (2961.4 cfs). The hatchery consists of a production pond system, where juvenile fish are reared, and two settling ponds. During daily operations, flows ranging from 7.75 to 15.5 mgd (719.5 to 1438.9 cfs) pass through the production and settling ponds and discharge directly into the Klamath River. These flows carry waste generated during the feeding and care of the fish including suspended solids, settleable solids, and chemicals used in disease control. When the fish production ponds are cleaned, flows ranging from 1.9 mgd to 5.5 mgd, comprised of metabolic wastes, unconsumed food, algae, silt, and detritus, are released to settling ponds, and then into the Klamath River.~~

Due to the relatively small discharge flows from Iron Gate Hatchery, and the minimal water quality data characterizing the quality of the discharge, the Klamath River TMDL model does not represent hatchery inputs. Therefore, the analysis of loads from the hatchery is based solely on empirical data.

4.2.3.1 Temperature

~~The current monitoring and reporting program for Iron Gate Hatchery does not require temperature monitoring~~Iron Gate Hatchery effluent temperatures were not measured prior to 2008. Effluent temperatures are currently measured as quarterly grab samples. Thus, ~~no~~ adequate temperature data are not available to evaluate the effects of the hatchery effluent on the Klamath River. Regardless, because the discharge of elevated temperature waste is not allowed per the interstate water quality objective for temperature, any effluent discharged to the river at a higher temperature than the river exceeds the interstate objective.

4.2.3.2 Nutrients and Organic Matter

Regional Water Board staff conducted a study from September to November 2004 to evaluate the hatchery discharge. Water to support hatchery operations is taken from the Iron Gate Reservoir from the deeper water layer. This water is aerated during transport to the hatchery. Flow through the hatchery remains relatively constant at ~~7.5~~16.1 million gallons per day. The hatchery discharges water at two locations: (1) the rearing pens and (2) the settling ponds. Nutrient concentrations measured from these two discharges were statistically compared.

The *Mann-Whitney U Test* was used to assess whether there is a significant difference between the distributions of concentrations for the two hatchery discharges. The test found there was no significant difference between the distributions of discharge concentration for both total phosphorus concentrations (p = 0.689) and total nitrogen concentration (p = 0.479). ~~The *Mann-Whitney U Test* was used to assess the difference between the two hatchery discharges. The test found there was no significant difference between the two discharges for both total phosphorus concentrations (p = 0.689) and total nitrogen concentration (p = 0.479).~~ Based on these results, the two discharges were combined and treated as a single discharge for the hatchery nutrient loading estimates.

There are two potential sources of loading associated with the hatchery operations. Nutrient loads may be added to the downstream Klamath River due to within-hatchery processes such as stock feeding. Nutrient loads may also be added to the downstream Klamath River due to the withdrawal of water from the deeper, nutrient-enriched water layer in Iron Gate Reservoir for hatchery operations.

To estimate the total nutrient loading for the hatchery, concentrations measured upstream of Iron Gate Reservoir were used as background to compare to the combined discharge concentrations for the rearing and settling pond discharges. Daily loads were determined for each date of the 2004 study. These daily loads were extrapolated to the next date that samples were collected. The total load for the study period (69 days) was determined and normalized to a daily load. Annual loads for total phosphorus and total nitrogen were calculated from these daily load estimates.

The median annual load to the Klamath River due to hatchery operations through the raceways and settling ponds was estimated to be -2109 lbs of total nitrogen and 567 lbs of total phosphorous. These results suggest that the hatchery is a relatively minor source of nutrients to the Klamath River. ~~The annual load to the Klamath River due to hatchery operations was estimated to be 1360 lbs of total nitrogen and 365 lbs of total phosphorous. These results suggest that the hatchery is a relatively minor source of nutrients to the Klamath River.~~ Organic matter loading of hatchery operations was not estimated since measurements of CBOD were not collected during the 2004 study.

4.2.4 Tributaries

4.2.4.1 Temperature

Regional Water Board staff evaluated whether the major Klamath River tributaries (Shasta, Scott, Salmon, and Trinity Rivers) are contributing to the temperature impairment of the Klamath River by analyzing the influence those tributaries have on the temperature of the Klamath River itself, as well as the potential for those tributaries to provide thermal refugia for salmonids and other cold water species. The approach to analyzing these issues required the estimation of natural tributary flows and temperatures.

Two Klamath River model scenarios ~~(TCT1 and TCT2)~~ were developed to evaluate the effects of the major Klamath River tributaries on the temperatures of the Klamath River, the natural conditions baseline scenario and the California allocation scenario, as described in Appendix 7~~Section 3.3.3.2~~. ~~TCT1 represents natural conditions baseline temperature conditions, and TCT2 represents the California temperature compliance scenario conditions.~~ Additional analyses were conducted to further understand how water management in the Shasta and Scott basins affects Klamath River temperature conditions, also described in Appendix 7~~Section 3.3.3.2~~. No additional analysis was conducted to evaluate effects of the Salmon River on the Klamath River, because the Salmon River TMDL found that current temperatures at the mouth of the Salmon River are consistent with the natural conditions baseline.

The natural conditions baseline scenario represents estimated natural flows and temperatures in the Shasta, Scott, and Trinity Rivers, as well as estimated natural temperatures in the Klamath River upstream of the major tributaries. A range of natural Scott River flow estimates was evaluated~~ due to the uncertainty of the natural flow estimates included in the natural conditions baseline scenario~~. The development of these scenarios is described in ~~Section 3.3.3.2~~Appendix 7.

The California ~~temperature compliance~~allocation scenario represents temperature conditions expected from full compliance with: 1) the Scott and Shasta TMDLs, 2) the Trinity Record of Decision (ROD), and 3) attainment of water quality standards in the Klamath River upstream (i.e. at stateline, Iron Gate, and Copco). The Shasta, Scott, and Trinity River ~~natural~~ temperature estimates used in this analysis are meant to depict the ~~absence of all anthropogenic impacts, representing full natural flows and site potential riparian shade conditions~~temperatures resulting from compliance with the Scott and Shasta TMDLs, and Trinity River Record of Decision. ~~The development of these scenarios is described in Section 3.3.3.2.~~

Shasta River
Under the California ~~compliance~~ allocation scenario the Shasta River would have a negligible temperature effect on the Klamath River. Figure 4.~~10~~ 14 presents the difference in maximum daily Klamath River temperatures downstream and upstream of the Shasta River for both the current condition and California ~~compliance~~ allocation scenarios. Figure 4.~~10~~ 14 shows that the Shasta River could have a slight warming effect on the Klamath River in the fall months under California compliant conditions, but there is only a small temperature difference (generally less than 0.5 ^{o}C (0.9 ^{o}F)) between the two simulation results otherwise.

Figure 4.15 presents the difference in maximum daily Klamath River temperatures downstream and upstream of the Shasta River for both current and natural conditions. The results of the natural conditions baseline scenario modeling analysis indicate that given natural temperature and flow conditions in the Klamath and Shasta Rivers, the Shasta River could cool the daily maximum temperature of the Klamath River by as much as ~~1.0 ^{o}C (1.8 ^{o}F)~~ 1.5 ^{o}C (2.7 ^{o}F) during the summer season, with ~~an average~~ typical reductions of 0.5 – 1.0 ^{o}C (0.9 – 1.8 ^{o}F) occurring from June through September. The Shasta River would be expected to reduce Klamath River temperatures 0.5 ^{o}C (0.9 ^{o}F) or less from October through mid-November, as it currently does. ~~Figure 4.11 15 presents the difference in maximum daily Klamath River temperatures downstream and upstream of the Shasta River for both current and natural conditions.~~

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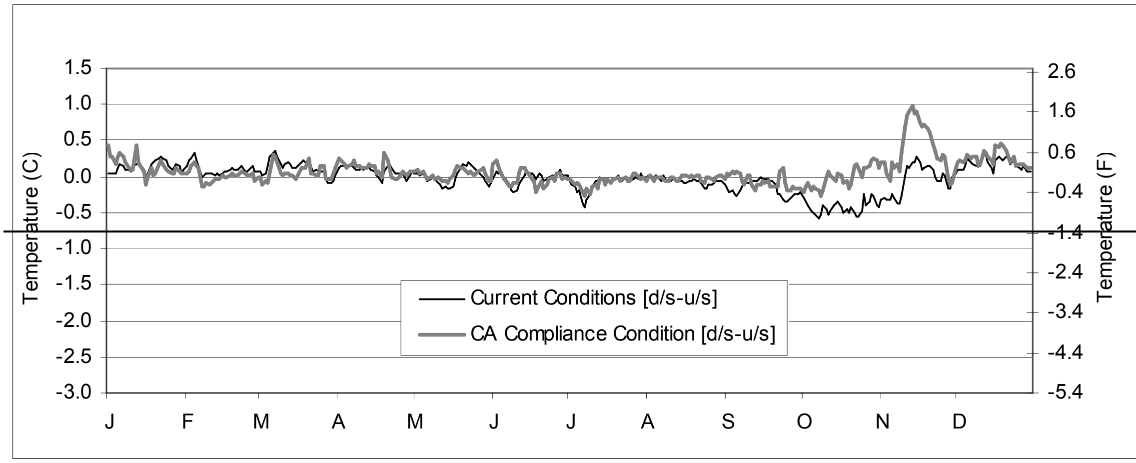


~~Figure 4.10: Change in Klamath River daily maximum temperatures resulting from current and Shasta TMDL compliant Shasta River conditions. Negative values indicate that the Shasta River is cooling the Klamath River.~~

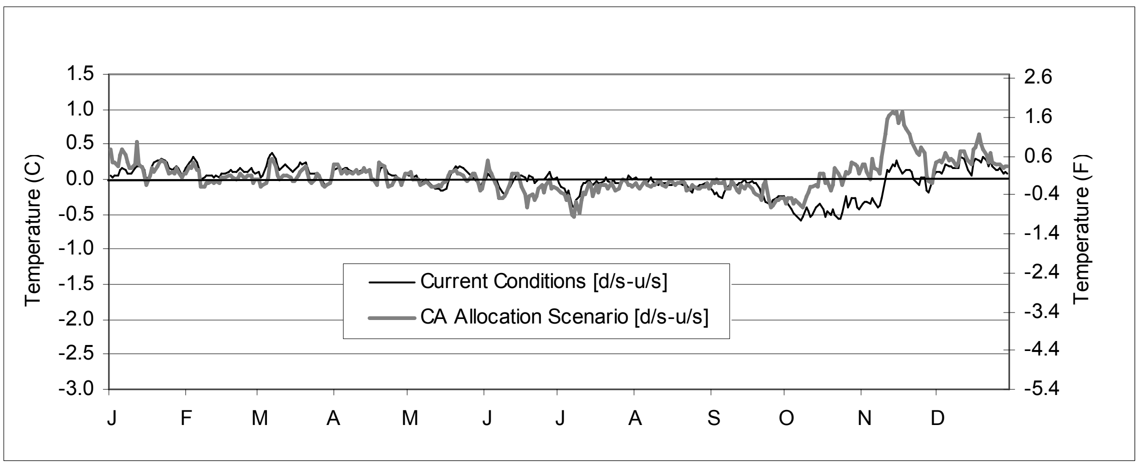
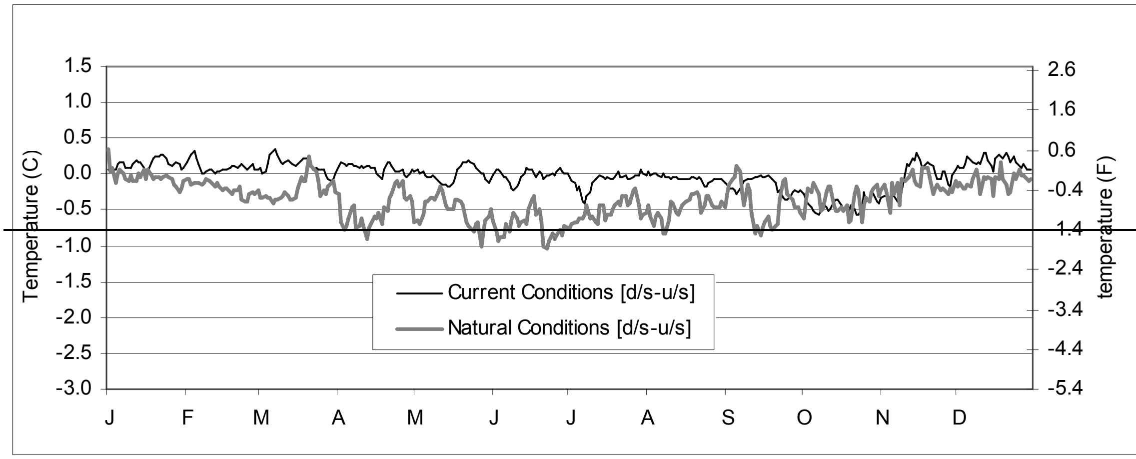


Figure 4.1~~0~~4: Change in Klamath River daily maximum temperatures resulting from current and Shasta TMDL compliant Shasta River conditions. Negative values indicate that the Shasta River is cooling the Klamath River.



~~Figure 4.11: Change in Klamath River daily maximum temperatures resulting from current and estimated natural Shasta River conditions. Negative values indicate that the Shasta River is cooling the Klamath River.~~

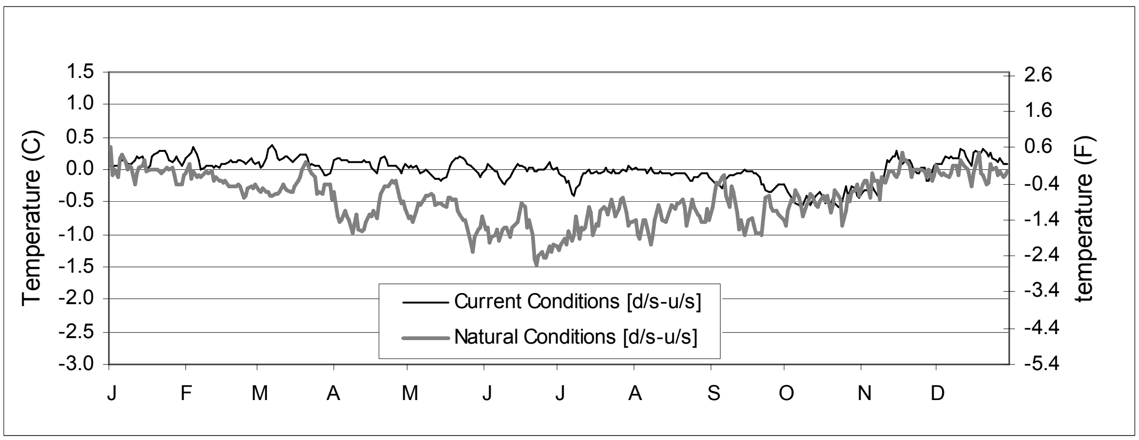
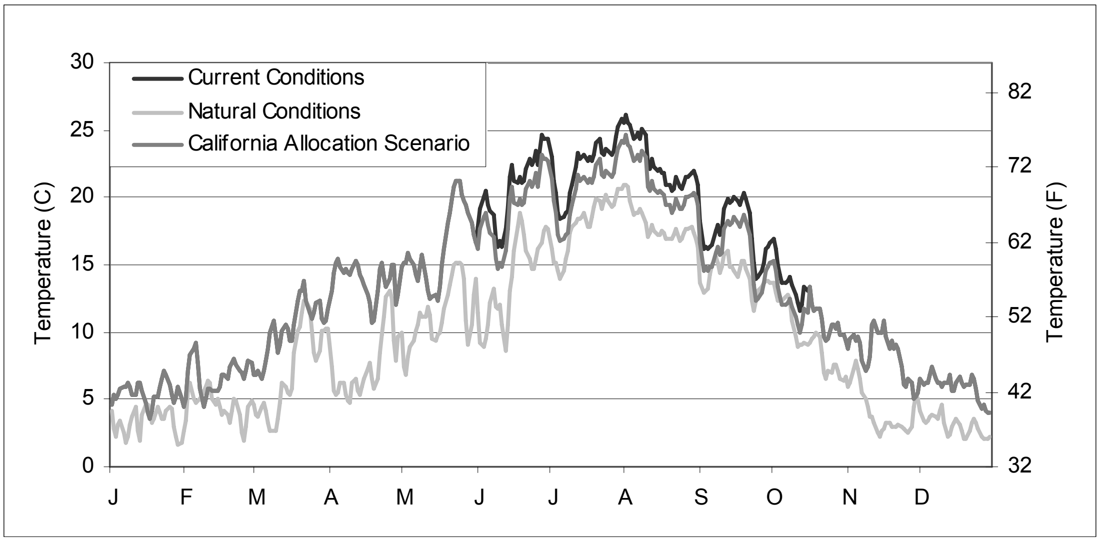


Figure 4.1~~1~~5: Change in Klamath River daily maximum temperatures resulting from current and estimated natural Shasta River conditions. Negative values indicate that the Shasta River is cooling the Klamath River.

Temperatures are too high to support adult salmonids when the 7-day average of the daily maximum temperatures exceeds 20 ^{o}C (68 ^{o}F), and too high to support juvenile salmonids when the 7-day average of the daily maximum temperatures exceeds 18 ^{o}C (64.4 ^{o}F) (see section 2.5.2). Currently, Klamath River temperatures regularly exceed 20 ^{o}C (68 ^{o}F) from July to September (see Figure 2.12, Dunsmoor and Huntington 2006). ~~Currently,~~ Shasta River temperatures are also currently too warm in the summer months to provide a thermal refuge for Klamath River salmonids. The California ~~compliance~~ allocation scenario assumes a 1.6 ^{o}C (2.9 ^{o}F) daily average temperature reduction relative to current conditions at the mouth of the Shasta River, based on the Shasta TMDL temperature analysis (Regional Water Board 2006). The 1.6 ^{o}C (2.9 ^{o}F) Shasta River temperature reduction depicted in the California allocation~~compliance~~ scenario improves conditions, but daily average temperatures are 20 ^{o}C (68 ^{o}F) or greater from mid-June to early September, as seen in Figure 4.~~12~~16. These temperatures are unsuitable for juvenile salmonids. The Shasta River temperature conditions depicted in the natural conditions baseline scenario, however, only exceed 20 ^{o}C (68 ^{o}F) for a few days during the year. Daily average temperatures greater than 20 ^{o}C (68 ^{o}F) are significant because temperatures above 20 ^{o}C (68 ^{o}F) ~~have been shown to inhibit~~ do not adequately support adult Chinook migration and holding (see section 2.5.2 and Appendix 4 [Carter 2008], Section 1.3.2). Thus, the results of this analysis indicate that the Shasta River would provide a thermal refuge for Klamath River salmonids under natural conditions, but would only provide adult salmonids a thermal refuge for a short time in the spring and fall under Shasta TMDL compliant conditions.



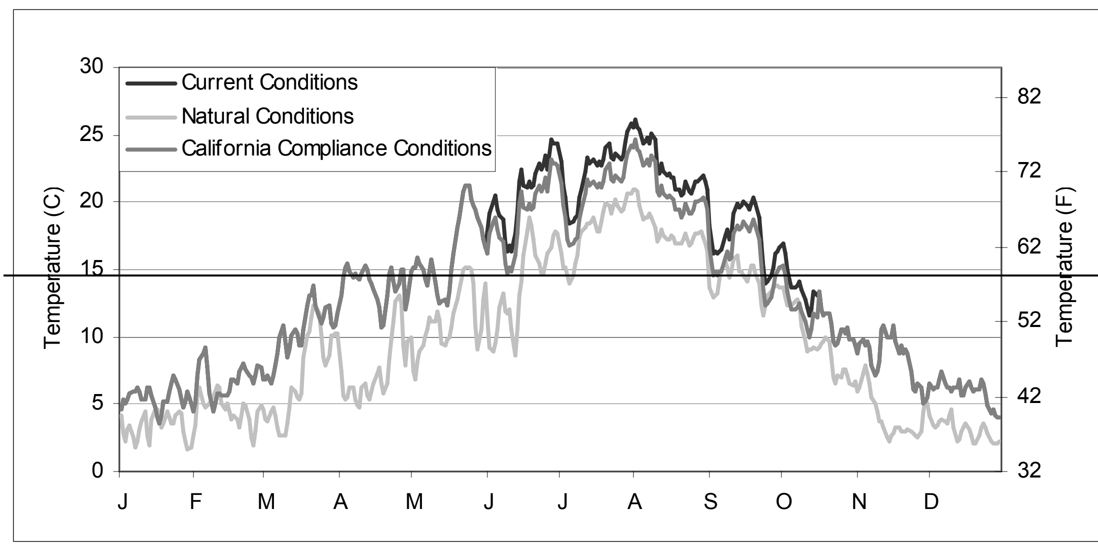


Figure 4.1~~2~~6: Estimated daily average Shasta River temperatures at the mouth of the Shasta River for the three management scenarios evaluated.

Scott River

The Scott River Temperature TMDL does not include a flow recommendation. The Scott River TMDL Action Plan requested Siskiyou County to conduct a groundwater study to further evaluate groundwater-surface water interactions in the Scott Valley. This work is in progress. The Klamath River TMDL California ~~temperature compliance~~

~~condition~~allocation scenario represents flows and temperatures consistent with the Scott River TMDL, ~~which~~ and includes current flows. The results of the California ~~compliance condition~~allocation scenario compared to current conditions are similar with respect to Klamath River temperatures downstream of the Scott River (Figure 4.~~13~~17). An exception occurs during the height of the spring snow melt, in late May, when the Scott River cools the Klamath River an additional 1.0 °C (1.8 °F) in the California ~~compliance~~ allocation scenario. Another exception occurs in the fall when the Scott River currently reduces the Klamath River temperature slightly, whereas it increases the Klamath River temperature slightly in the California ~~compliance~~ allocation scenario. The difference is a result of the fact that in the California ~~compliance~~ allocation scenario the Klamath River is much cooler during those months, compared to the current conditions scenario. The Scott River has nearly the same effect on the Klamath River in the two scenarios during the remainder of the ~~season~~year.

The results of the natural conditions baseline scenario indicate the Scott River could potentially have a more significant temperature influence on the Klamath River under natural conditions, reducing temperatures by ~~over 1.5 °C (2.7 °F) and as much as 3.0~~ 2~~3~~.0 °C (3.6~~5.4~~ °F) in June, which amounts to as much as an additional 1.0 -°C (~~5.4~~1.8 °F) reduction below the current conditions scenario~~ in June~~. The additional Klamath River temperature reduction gradually decreases to 0 by September ~~, and reducing temperatures by 0.5 - 1.0 °C (0.9 – 1.8 °F) during the remainder of the summer season~~ (Figure 4.~~14~~18). ~~These results, however, reflect the most generous estimates of natural Scott River flows and temperatures. Given Regional Water Board staff belief that the Scott River flows represented in the natural conditions baseline scenario are likely too high (and temperatures too low), staff have developed more refined estimates of natural flow and temperatures, as detailed in Section 3.3.3.2. Staff evaluated how the Klamath River would be affected, given these refined Scott River natural flow and temperature estimates. The effect on Klamath River temperatures was assessed outside of the Klamath TMDL models, and was calculated using the mixing equation. The result of this additional analysis is presented in Figure 4.15. The results indicate that the Scott River would likely have a more negligible effect on Klamath River temperatures under these refined natural flow and temperature conditions than depicted in the natural conditions baseline scenario.~~

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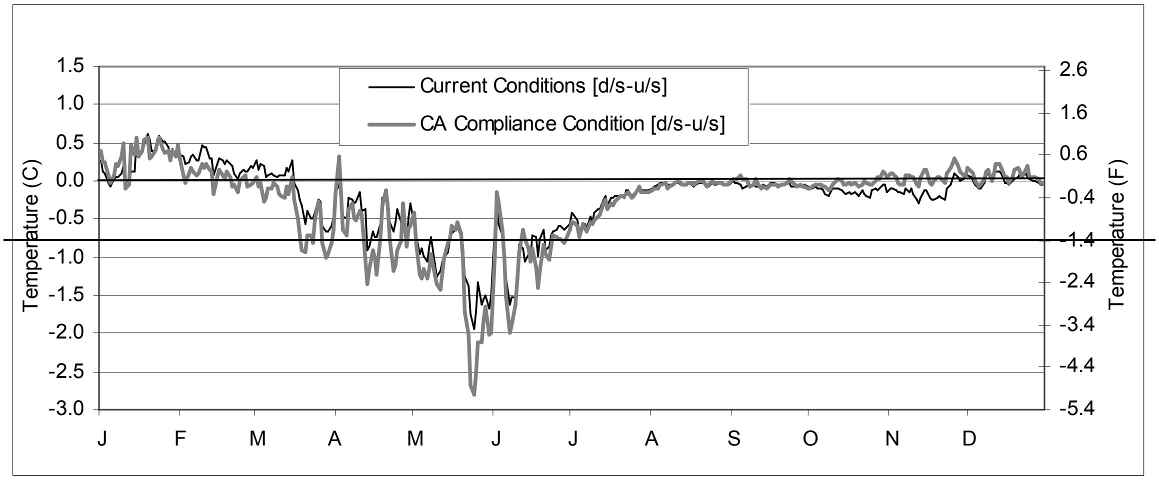
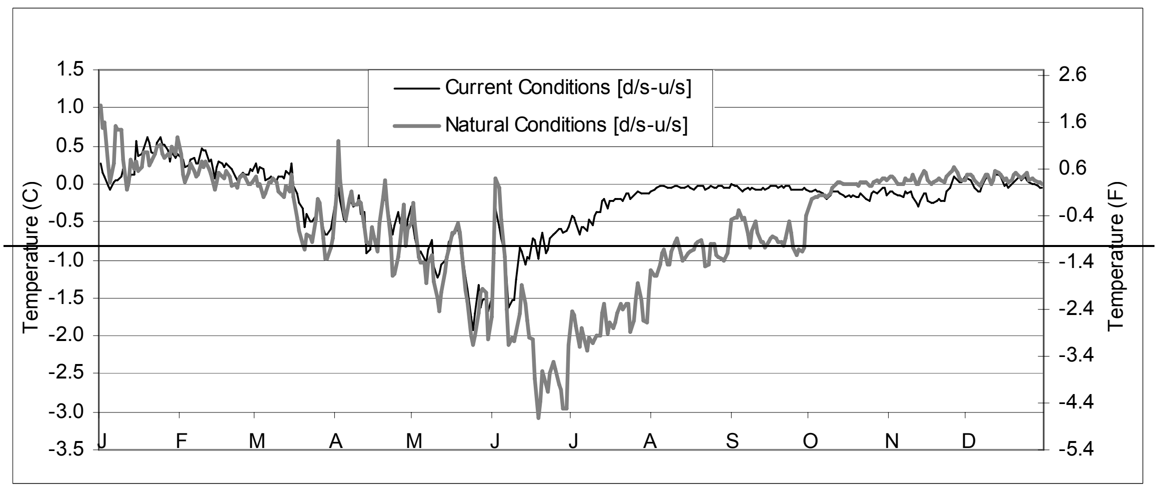


~~Figure 4.13: Change in Klamath River daily maximum temperatures resulting from current and Scott TMDL compliant Scott River conditions. Negative values indicate that the Scott River is cooling the Klamath River.~~



~~Figure 4.14: Change in Klamath River daily maximum temperatures resulting from current and originally estimated natural Scott River conditions. Negative values indicate that the Scott River is cooling the Klamath River.~~

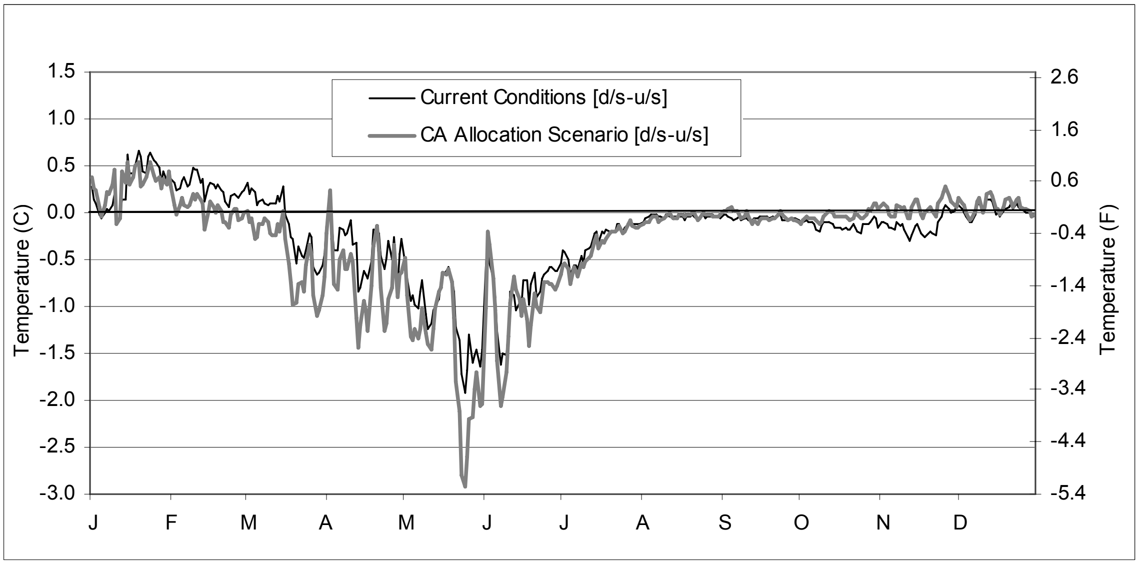


Figure 4.1~~3~~7: Change in Klamath River daily maximum temperatures resulting from current and Scott TMDL compliant Scott River conditions. Negative values indicate that the Scott River is cooling the Klamath River.

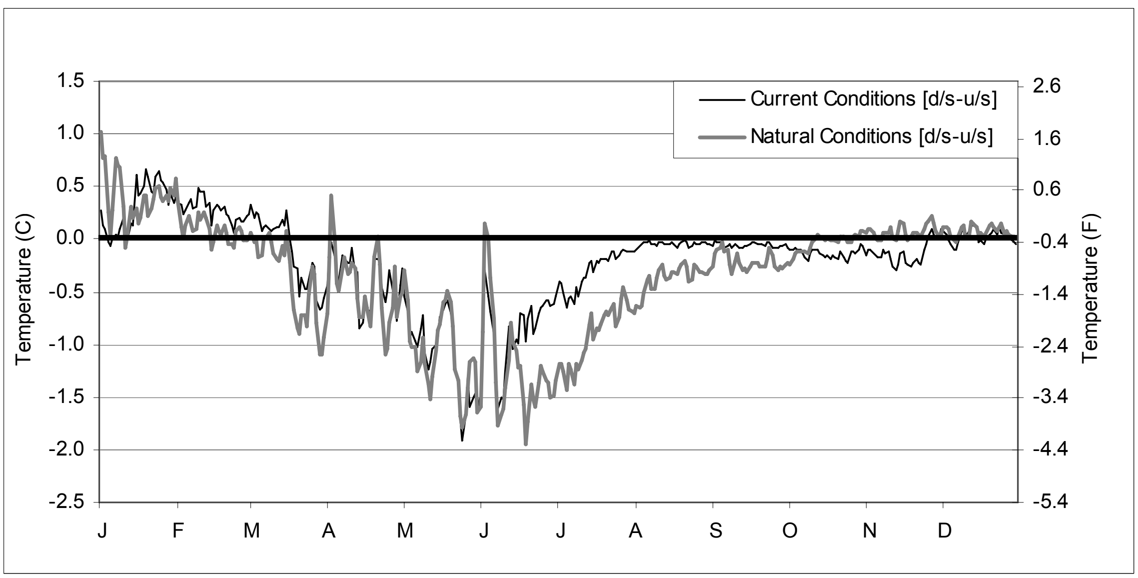
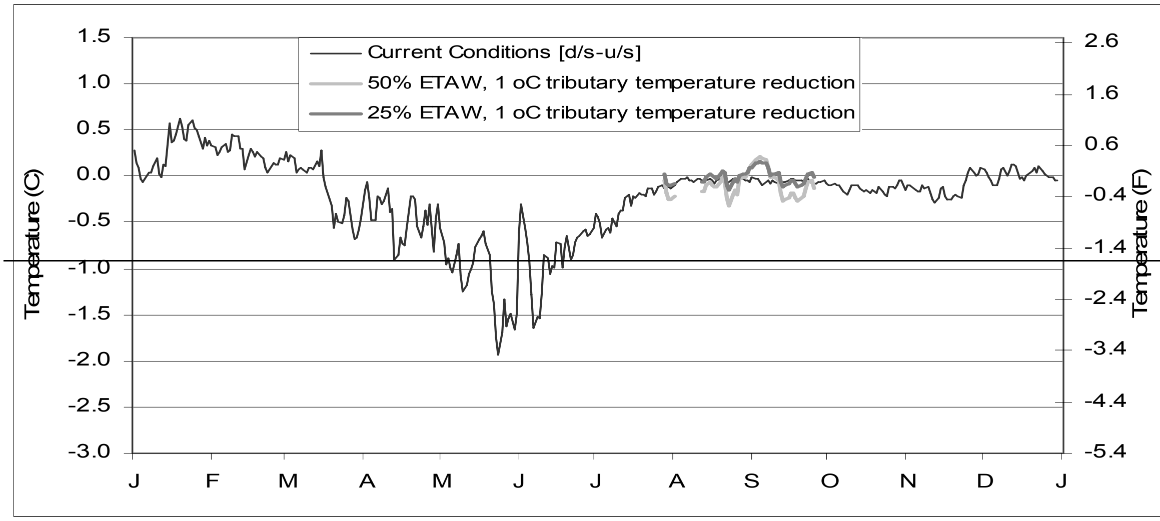
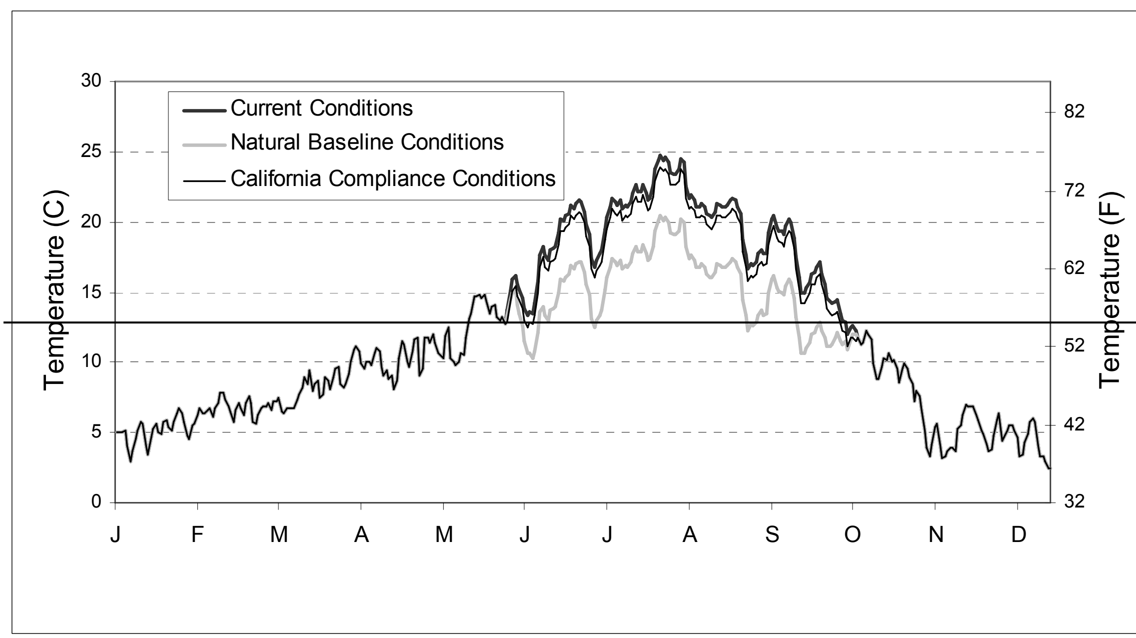


Figure 4.1~~4~~8: Change in Klamath River daily maximum temperatures resulting from current and estimated natural Scott River conditions. Negative values indicate that the Scott River is cooling the Klamath River.



~~Figure 4.15~~19: ~~Change in Klamath River daily maximum temperatures resulting from current and revised natural Scott River conditions estimates. Negative values indicate that the Scott River is cooling the Klamath River.~~

Current Scott River temperatures from June to October are too hot to offer salmonids a thermal refuge from the high temperatures of the Klamath River. The results of the natural conditions baselines scenario indicate the Scott River would provide a ~~marginal~~ thermal refuge during early and late summer under those conditions (Figure 4.~~16~~19). Such conditions would provide migrating adult salmonids a thermal refuge during their upstream migration prior to spawning, but would not support juvenile rearing throughout the summer. ~~The additional analysis conducted by Regional Water Board staff indicates the conditions depicted in the natural conditions baseline are likely to overestimate natural flows and underestimate natural temperatures.~~



~~Figure 4.16: Estimated daily average Scott River temperatures at the mouth of the Scott River for three scenarios.~~

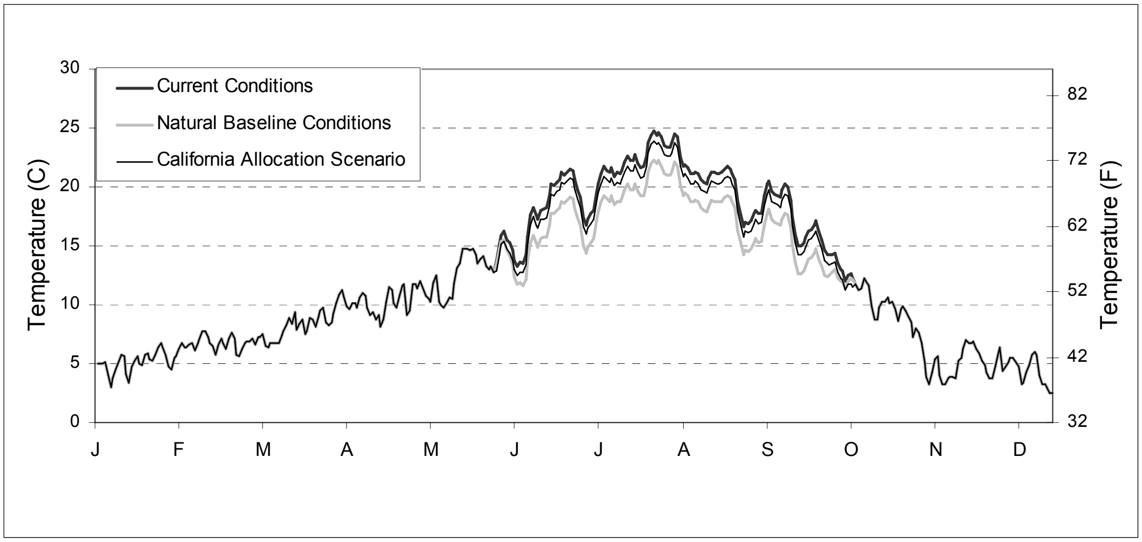
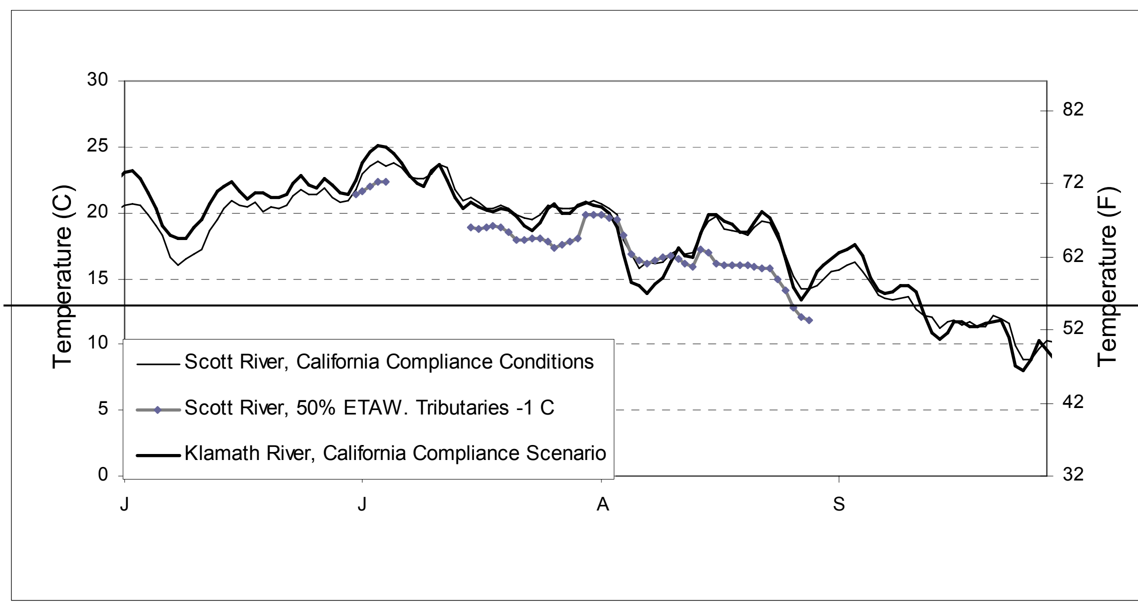


Figure 4.~~16~~19: Estimated daily average Scott River temperatures at the mouth of the Scott River for three scenarios.

~~The natural flow estimate developed using the "50% evapotransporation of applied water (ETAW)" flow estimate and 1.0 °C (1.8 °F) reduction in tributary temperatures, described in Section 3.3.3.2, provides a more likely estimate of natural flow and temperature conditions. Figure 4.17 21 presents temperature estimates for two of the Scott River scenarios, as well as the temperatures compliant with California water quality standards in the Klamath River upstream of the Scott River. The results of the 50% ETAW estimate indicate the Scott would provide marginal thermal refuge during the late summer when adult salmonids are preparing for spawning.~~



~~Figure 4.17: Comparison of estimated daily average Scott River Temperature conditions to estimated daily average Klamath River conditions.~~

Trinity River
The California ~~compliance~~ allocation scenario modeling analysis indicates that natural Trinity River flows, as well as those prescribed by the ROD, have a moderate cooling effect on the Klamath River downstream of the Trinity River. Figure 4.~~18~~ 20 presents the difference in daily maximum Klamath River temperatures downstream and upstream of the Trinity River for both current and Trinity ROD flow (i.e., California allocation scenario) conditions~~natural conditions~~. Similarly, Figure 4.~~19~~ 21 presents the difference in daily maximum Klamath River temperatures downstream and upstream of the Trinity River for both the year 2000 (current condition scenario) and natural conditions. ~~Trinity ROD flow (i.e., California compliance scenario) conditions~~.

It is important to note that the upstream temperatures in the natural conditions baseline and California ~~compliance~~ allocation scenarios reflect the absence of upstream reservoirs, as well as the effects of the estimated natural Shasta and Scott River inputs. These results are most apparent when comparing the difference between the estimated natural and Trinity ROD flow (i.e. California ~~compliance~~allocation) conditions. As discussed in Section 3.3.3.2, the estimated natural Trinity River flows and the Trinity ROD flows are equal during the summer months. However, under the California ~~compliance~~ allocation scenario, the Trinity ROD flow has a bigger effect downstream -from June to October because the Klamath River temperatures upstream are warmer in comparison to the natural conditions scenario.

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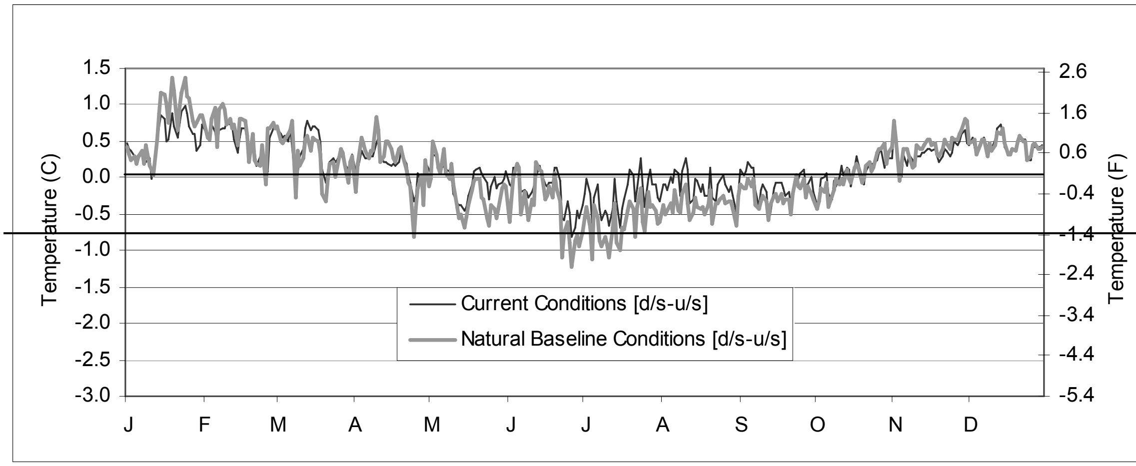
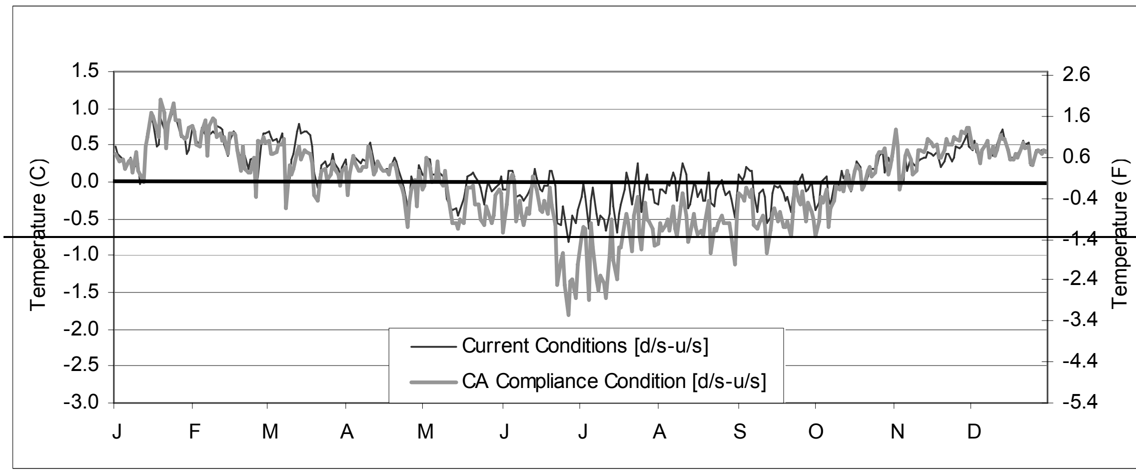


~~Figure 4.18: Change in Klamath River daily maximum temperatures resulting from current and estimated natural Trinity River conditions. Negative values indicate that the Trinity is cooling the Klamath River.~~



~~Figure 4.19: Change in Klamath River daily maximum temperatures resulting from current and Trinity ROD compliant Trinity River conditions. Negative values indicate that the Trinity River is cooling the Klamath River.~~

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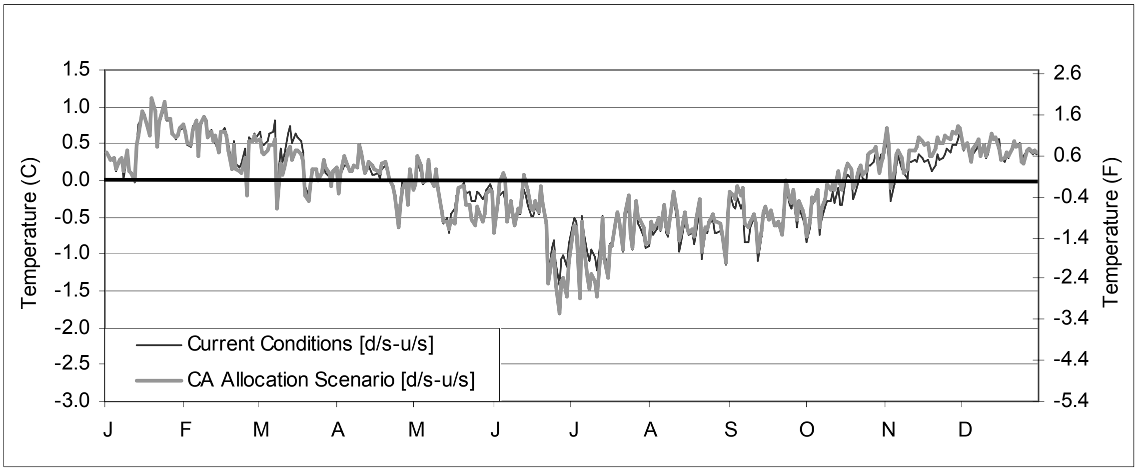

Figure 4.~~18~~20: Change in Klamath River daily maximum temperatures resulting from current and Trinity ROD compliant Trinity River conditions. Negative values indicate that the Trinity is cooling the Klamath River.

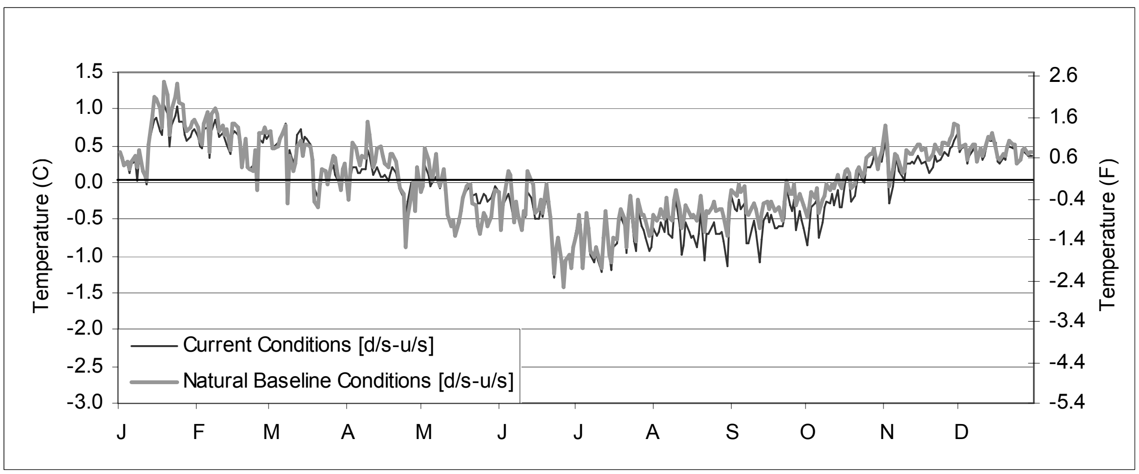

Figure 4.~~19~~21: Change in Klamath River daily maximum temperatures resulting from current and estimated natural Trinity River conditions. Negative values indicate that the Trinity River is cooling the Klamath River.

Effects of Shade on Klamath River Tributaries

Temperature TMDLs have been established for twelve watersheds in the north coast region of California. These watersheds include three of the major Klamath River tributaries: the Salmon, Scott, and Shasta River watersheds. All twelve temperature TMDLs have evaluated the effects of shade on stream temperatures and each of these analyses have consistently reached the same conclusion regarding stream shade: the temperature of a stream is significantly influenced by the amount of solar radiation the stream receives. A second conclusion of these analyses is that changes in streamside vegetation affect shade (and thus, temperature) to a greater degree in smaller streams than in large streams. This is largely due to the fact that the height of trees is greater in relation to stream width in smaller streams, whereas trees are less effective at casting shade on larger streams. These conclusions are consistent with published literature and temperature analyses conducted in the Pacific N~~n~~orthwest (Independent Multidisciplinary Science Team, 2000; Johnson, 2004; Miner and Godwin, 2003; ODEQ, 2002).

Regional Water Board staff evaluated the sensitivity of Klamath River tributaries to the effects of solar radiation using the USGS stream reach temperature model SSTEMP. That analysis of six moderate-sized tributaries (Indian, Elk, Clear, Dillon, Red Cap, and Bluff Creeks) confirms the importance that solar radiation loads have in determining stream temperatures (Wilder, 2007).

Given the similarity of Klamath River tributaries to other north coast watersheds, and the universal nature of the laws of thermodynamics, Regional Water Board staff have determined that the conclusions of shade-related analyses from previous temperature TMDLs stated above apply region-wide, and especially to Klamath tributaries not already assigned TMDL shade allocations. Riparian shade controls are needed in many Klamath River tributaries not subject to an existing TMDL Action Plan.

Effects of Sediment Loads on Klamath River Tributaries

Historic increases in sediment loads have resulted in the widening of stream channels, reduction of riparian shade, and consequent elevation of stream temperatures. The primary causes of increased sediment loads are both natural and human-caused mass wasting. The US Forest Service has estimated that 446 of the 2260 (20%) total stream miles evaluated within Klamath National Forest lands were significantly altered during the flood of 1997 (De la Fuente and Elder, 1998). Much of the damage done to stream channels happened when debris slides that had initiated in the headwater areas resulted in debris torrents that traveled long distances (up to many miles), and in the process severely disrupted stream channels and removed riparian vegetation. Temperature data from one of the affected streams, Elk Creek, showed that in the summer after the flood, the peak temperature was the highest of seven years of record, and was 2.1 ^{o}C (3.8 ^{o}F) higher than the average from 1990-1995. Likewise, the diurnal variation increased to 6.9 ^{o}C (12.5^{o}F), 2.7 ^{o}C (4.9 ^{o}F) higher than the 1990-1995 average.

Regional Water Board staff (Wilder, 2007) evaluated the sensitivity of Klamath River tributaries to the effects of channel widening, using the USGS stream reach temperature model SSTEMP. The results of that analysis show that daily average stream temperatures can increase in the range of 1 ^{o}C to 2 ^{o}C when the wetted channel width doubles. However, these results are conservative given that the analysis only evaluated the effects of a change in wetted width and did not consider the loss of riparian vegetation (and consequent decrease in shade) that occurs when the active channel increases in width following a debris torrent or aggradation event. Furthermore, because the downstream endpoints of the modeled reaches are near the mouths of the streams where streams are already near equilibrium, it is likely that even larger temperature increases would occur in some reaches upstream where the difference between the current temperature and the equilibrium temperature is greater. Regional Water Board staff have also identified an apparent correlation of decreases in temperature with decreases in channel width in thermal infrared survey data collected in 2004 by Watershed Sciences, LLC.

Increased sediment loads in tributary streams also create temperature impacts associated with loss of thermal refugia in the Klamath mainstem. Because the daily maximum temperatures of the Klamath mainstem are at lethal levels through most of the summer, the opportunity for salmonids to rear in the mainstem during those times depends on access to thermal refugia. The majority of thermal refugia in the Klamath mainstem are located at the mouths of cold tributaries where they mix with the Klamath River (Belchik 1997). The volume of thermal refugia at tributary mouths can be greatly affected by the sediment loads of the tributaries. Higher sediment loads can cause tributaries to infiltrate into gravels before reaching the river, create barriers that restrict fish from entering tributaries, and fill in pools where cold water exists. Four of the five largest (>1000 ft^2) thermal refuge areas between Iron Gate Dam and Seiad Valley are created by tributaries that were significantly impacted by sediment loads during the 1997 flood event (Belchik 1997; Keir Associates 1999).

4.2.4.2 Effects of Suction Dredging on Thermal Refugia

The proper functioning of thermal refugia areas in the Klamath River Basin is necessary to meet the Basin Plan water temperature objective since these areas of cold water in the mainstem Klamath River are representative of natural water temperatures. In expert testimony, Dr. Peter Moyle (Moyle, 2006) stated that:

> Suction dredging represents a chronic unnatural disturbance of natural habitats that are already likely to be stressed by other factors and can therefore have a negative impact on fishes that use the reach being dredged. All anadromous fishes in the Klamath Basin should be considered to be in decline and ultimately threatened with extirpation. Suction dredging, through a combination of disturbances of resident fish, alteration of substrates, and indirect effects of heavy human uses of small areas, especially thermal refugia, will further contribute to the decline of the fishes.

Studies are available which describe the impacts of suction dredging on streams and aquatic organisms, although ~~While~~ Regional Board staff are not aware of any scientific studies that directly evaluate the impacts of suction dredging on thermal refugia.~~,~~ ~~there are studies that generally describe the impacts of suction dredging on streams and aquatic organisms.~~ Based on these studies, Regional Board staff have concluded that suction dredging has the potential to impact thermal refugia in the Klamath River through the following mechanisms, among others:

1. Changes to channel substrate composition can affect fish, macroinvertebrates, and floral components of stream ecosystems (US District Court, 2004). In one study, the number of rainbow trout in a small pool in Butte Creek, California declined by 50% after dredging upstream (Harvey et. al, 1998).
2. Streambed and bank destabilization resulting from channel excavations and the hand-sorting by divers of cobble too large to pass through the dredge may increase scour and fill in areas previously unaffected by dredging (US District Court, 2004).

3. Stream channel morphology and substrate composition can be altered as rocks, gravel, and silt are scoured away and then deposited in a different location within a stream; often in previously undisturbed areas (US District Court, 2004).
4. Pools can be filled by sediment mobilized by upstream dredging. In the Harvey study, suction dredging upstream filled 25% of the volume of a pool downstream.

The following impacts were documented in the California Department of Fish and Game Draft Environmental Impact Statement (CDFG, 2003) for the adoption of regulations for suction dredge mining:

1. Harvey (1986) reported that a 50-foot reach of a tributary to Butte Creek was completely channelized and riffles were transformed into exposed gravel bars by a 10-day operation by one dredge.
2. In many instances, suction dredgers working close to streambanks undercut and destroy the integrity of the bank, destabilizing the bank and removing its protective vegetation and other important habitat features including rocks, protruding logs and root wads.
3. Stern (1998) reported that undercutting of stream banks was the most common adverse impact on Canyon Creek. Thirty-four percent of the suction dredgers observed were undercutting stream banks.

4.2.4.3 Nutrients and Organic Matter

Current annual nutrient and CBOD loads from the California tributaries to the Klamath River are presented in Figure 4.~~20~~22. Loads are presented for the Shasta, Scott, Salmon, and Trinity Rivers, and for groups of tributaries located between each of the major tributaries. These loads were calculated based on the best available quality assured concentration data from 2000 through 2007 and flows from the 2000 calendar year. A description of the sources of the data and the methodologies used to calculate the tributary loads is provided in Appendix 6. Cumulatively the California tributary loading comprises the following percentage of the total annual loads estimated for the Klamath River: 55% TP; 62% TN; and 72% CBOD. California tributaries below Iron Gate also contribute the largest amount of ~~the~~ flow volume to the river, generally at lower nutrient concentrations compared with the lower flows, but higher concentrations from the upper basin. Most tributaries have nutrient and CBOD concentrations that are regarded to be at or below concentrations considered to be reference conditions for the region (US EPA 2000). There are exceptions, such as Shasta River and Bogus Creek.

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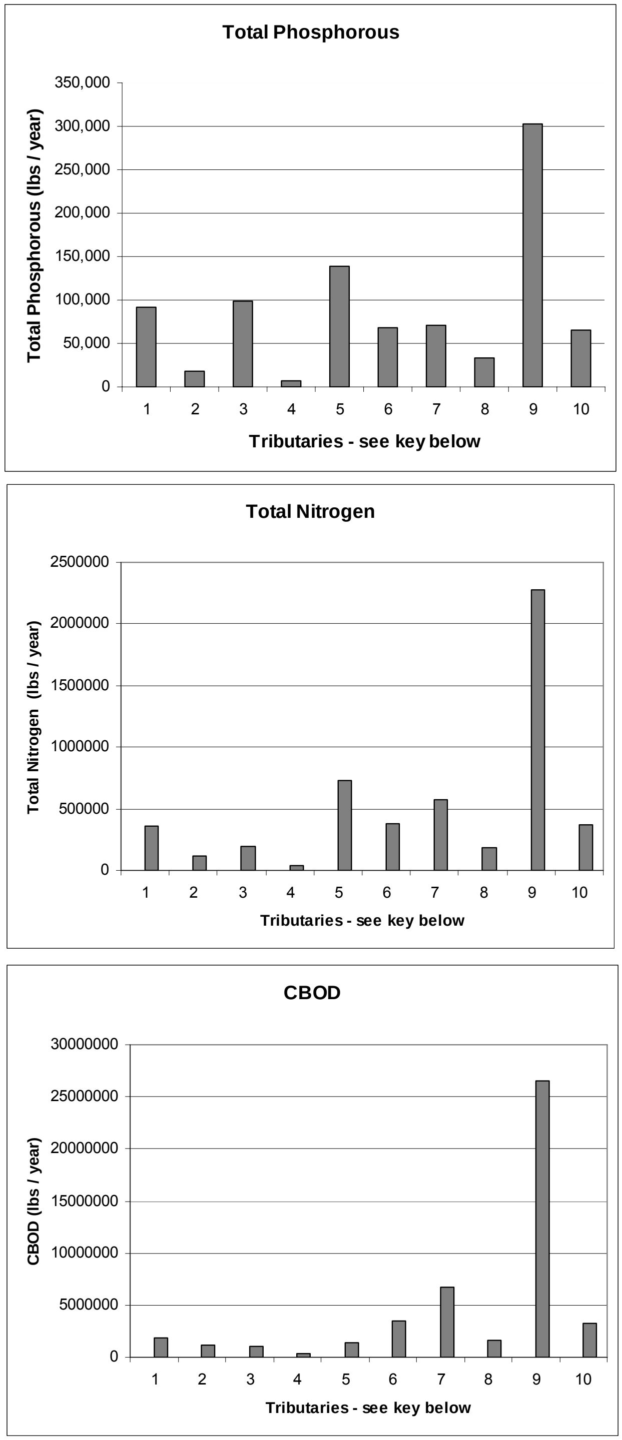

Stations List:

1-	Stateline to Iron Gate Tributaries	2-	Iron Gate to Shasta Tributaries
3-	Shasta River	4-	Shasta to Scott Tributaries
5-	Scott River	6-	Scott to Salmon Tributaries
7-	Salmon River	8-	Salmon to Trinity Tributaries
9-	Trinity River	10-	Trinity River to Turwar Tributaries

Figure 4.~~20~~22: Current Total Annual Loading (Pounds/Year) of Total Phosphorus, Total Nitrogen, and CBOD to the Klamath River from California Tributaries

The Shasta River Temperature and Dissolved Oxygen TMDLs include load allocations and implementation actions, which when achieved will result in reduced nutrient and organic matter loads delivered to the Klamath River. For the Klamath River TMDL's California ~~dissolved oxygen compliance~~allocation scenario, the nutrient and CBOD loads from the Shasta River were calculated based on Shasta River TMDL compliant conditions, as described in Appendix 7. These TMDL compliant Shasta River loads reflect the expected annual loads to the Klamath River when the Shasta River TMDL is fully implemented and nutrient/ biostimulatory substances and DO water quality objectives within the Shasta River are achieved. Figure 4.~~21~~ 23 compares current and California ~~dissolved oxygen compliance~~allocation scenario TP, TN, and CBOD loads from the Shasta River. The California ~~dissolved oxygen compliance~~allocation scenario conditions represent 72%, 59%, and 18% reductions, respectively, from current TP, TN, and CBOD loads delivered from the Shasta River to the Klamath River.

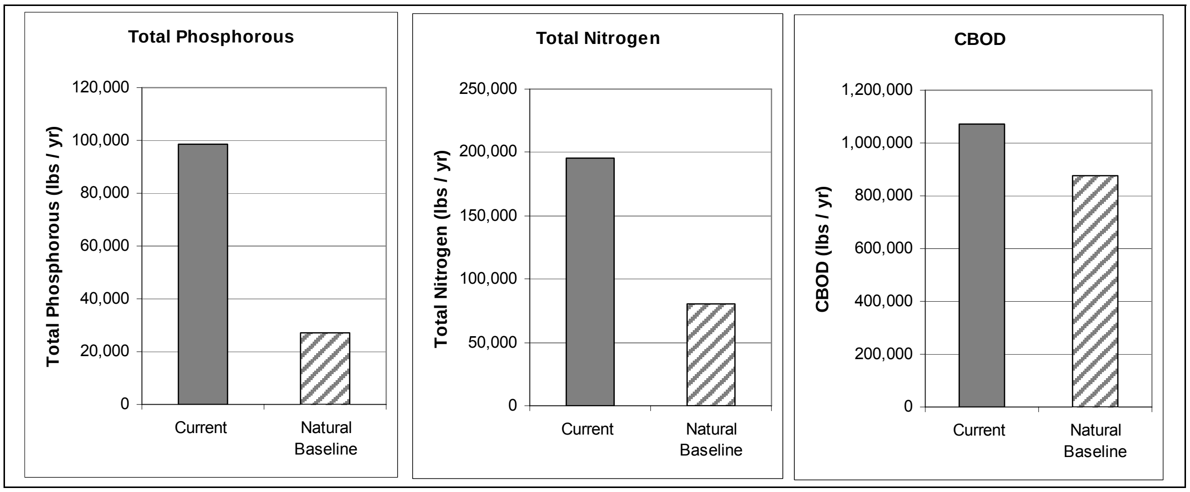

Figure 4.~~21~~23: Shasta River Comparison of Current Loads (pounds/year) of TP, TN, and CBOD with Natural Conditions Baseline Loads.

For the California ~~dissolved oxygen compliance~~allocation scenario, the nutrient and CBOD loads at the mouths of the other California tributaries (except Bogus Creek) were represented as the average of the available quality assured concentration data from 2000 through 2007 and flows from the 2000 calendar year. This representation of average tributary nutrient and CBOD loads is sufficient to meet dissolved oxygen and biostimulatory substances objectives in the Klamath River. ~~The nonpoint source nutrient control measures identified in the implementation plan will, however, apply to these tributaries in order to maintain the loads necessary to meet the Klamath River standards.~~

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CHAPTER 4. REFERENCES

Asarian, E. and J. Kann. 2009. (Draft) Nutrient Budgets Dynamics in Iron Gate and Copco Reservoirs, California, May 2005 – December 2007. Final Technical Report to the Karuk Tribe Department of Natural Resources, Orleans, CA.

Bachman, R.W. 1980. Prediction of total nitrogen in lakes and reservoirs. Pp. 320-324 in Restoration of Lakes and Inland Waters: Proceedings of an International Symposium on Inland Waters and Lake Restoration, Portland, ME. EPA-440/5-81-010. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Belchik, M. 1997. Summer Locations and Salmonid Use of Cool Water Areas in the Klamath River. Iron Gate Dam to Seiad Creek, 1996. Yurok Tribal Fisheries Program. Klamath, CA. 13pp.

California Department of Fish and Game (CDFG). 1993. Draft Environmental Impact Report: Adoption of Regulations for Suction Dredge Mining. State of California, the Resources Agency, Department of Fish and Game. October 1993. 188 pp.

Carter, K. 2008. Effects of Temperature, Dissolved Oxygen/Total Dissolved Gas, Ammonia, and pH on Salmonids. North Coast Regional Water Quality Control Board. Santa Rosa, CA. 47pp.

Danosky and Kaffka, 2002, Farming Practices and Water Quality in the Upper Klamath Basin, Final Report to the California State Water Resources Board.

Dunsmoor, L.K., and C.W. Huntington. 2006. Suitability of Environmental Conditions within Upper Klamath Lake and the Migratory Corridor Downstream for Use by Anadromous Salmonids. Technical Memorandum to the Klamath Tribes. Revised October 2006. 80 pp. + appendices.

De la Fuente, J. and D. Elder. 1998. The flood of 1997, Klamath National Forest, Phase I Final Report. November 24, 1998. Klamath National Forest. Yreka, CA. 76 p. plus appendices.

Harvey, B. C. and T. E. Lisle. 1998. Effects of suction dredging on streams: a review and an evaluation strategy. *Fisheries* 23:8–17.

Hicks, 2009, Comments to North Coast Regional Water Quality Control Board on Public Review Draft of Klamath River TMDL and Action Plan. United State Department of the Interior, Bureau of Reclamation, Klamath Basin Area Office, Klamath Falls, Oregon. Accessed at http://www.swrcb.ca.gov/northcoast/water_issues/programs/tmdls/klamath_river/klamath_river_tmdl_comments.shtml on 10/27/2009.

Independent Multidisciplinary Science Team (IMST). 2000. Influences of human activity on stream temperatures and existence of cold water fish in streams with elevated temperature: report of a workshop. Technical report 2000-2 to the Oregon Plan for Salmon and Watersheds: Oregon Watershed Enhancement Board. Salem, Oregon. 35 p. plus appendices.

Johnson, S. L. 2004. Factors influencing stream temperatures in small streams: substrate effects and a shading experiment. Canadian Journal of Fisheries and Aquatic Sciences. (61): 913-923.

Kann, J. and E. Asarian. 2007. Nutrient Budgets and Phytoplankton Trends in Iron Gate and Copco Reservoirs, California, May 2005 - May 2006. Submitted to the State Water Resources Control Board, Sacramento, CA by the Karuk Tribe of California, Department of Natural Resources, Orleans, CA.

Kann, J. and W. Walker. 2001. Nutrient and hydrological loading to Upper Klamath Lake, Oregon, 1991–1998. Prepared for the Klamath Tribes Natural Resources Department and the Bureau of Reclamation. Klamath Falls, Oregon. 48 p. plus appendices.

McCarthy, K and Johnson, H.M, 2009. U.S. Geological Survey Scientific Investigations Report 2009–5030, Effect of Agricultural Practices on Hydrology and Water Chemistry in a Small Irrigated Catchment, Yakima River Basin, Washington

Miner, J.R. and D. Godwin. 2003. Documenting progress toward achieving stream temperature compliance in Oregon TMDL plans. Oregon State University Extension. Salem, Oregon. 10 pp.

Moisander, P. 2008. Presentation to the Klamath Blue-Green A~~a~~lgae Work Group (Sacramento) - Diversity and nutrient limitation of *Microcystis* in Klamath River reservoirs. University of California Santa Cruz, Ocean Sciences Department.

Moyle, Peter B. 2006. Declaration of Peter B. Moyle, Ph.D., in Support of Entry into Stipulated Judgment. Superior Court of California. C/A No. RG 05 211597. January 2006. 10 pp.

National Research Council of the National Academies (NRC). 2004. Endangered and Threatened Fishes in the Klamath River Basin. Washington, D.C. National Academies Press.

Nürnberg, G. K, 1984. The prediction of internal phosphorus loading in lakes with anoxic hypolimnia. *Limnol. Oceanogr.*, 29: 111-124.

Oregon Department of Environmental Quality (ODEQ). 2002. Upper Klamath Lake Drainage Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP).

PacifiCorp. 2009. Water Quality Conditions During 2008in the Vicinity of the Klamath Hydroelectric Project. Prepared by: Richard Raymond, E&S Environmental Chemistry, Inc., Corvallis, Oregon. Prepared for: CH2M Hill, 2020 SW 4th Avenue, 3rd Floor, Portland, OR 97201; and PacifiCorp Energy, 825 N.E. Multnomah, Suite 1500, Portland, OR 97232. May 22, 2009

PacifiCorp. 2008. Water Quality Conditions During 2007 in the Vicinity of the Klamath Hydroelectric Project. Prepared by: Richard Raymond, E&S Environmental Chemistry, Inc., Corvallis, Oregon. Prepared for: CH2M Hill, 2020 SW 4th Avenue, 3rd Floor, Portland, OR 97201; and PacifiCorp Energy, 825 N.E. Multnomah, Suite 1500, Portland, OR 97232. October 14, 2008.

PacifiCorp. 2006. Causes and Effects of Nutrient Conditions in the Upper Klamath River. Klamath Hydroelectric Project (FERC Project No. 2082). PacifiCorp, Portland, Oregon. November 2006. 77 pp.

Reckhow, K.H. and S.C. Chapra. 1983. Engineering Approaches For Lake Management – Volume 1: Data Analysis and Empirical Modeling. Butterworth Publishers – Ann Arbor Science Book. pp:105.

Rykbost, K.A and Charlton, B.A, 2001, Nutrient Loading of Surface Waters in the Upper Klamath Basin: Agriculture and Natural Sciences, Special Report 1023, Agricultural Experiment Station, Oregon State University, March 2001. Can be accessed at http://ir.library.oregonstate.edu/jspui/handle/1957/6244

Tetra Tech. 2008. Nutrient Dynamics in the Klamath. Prepared for U.S. EPA Region 9 and North Coast Regional Water Quality Control Board. February 12, 2008. Tetra Tech, Inc., Research Triangle Park, NC.

Walker, W.W. 2001. Development of a Phosphorus TMDL for Upper Klamath Lake, Oregon. Oregon Department of Environmental Quality. March 7, 2001.

Watershed Sciences, LLC. 2004. Aerial Surveys using Thermal Infrared and Color Videography: Scott River and Shasta River Sub-Basins. Prepared for the North Coast Regional Water Quality Control Board and University of California Davis. February 26, 2004. 39 pp. + appendix.

US District court for the Northern District of California (US District Court), 2004, Karuk Tribe of California, Plaintiff, vs. United States Forest Service; Jeff Walter, Forest Supervisor, Six Rivers National Forest; Margaret Boland, Forest Supervisor, Klamath National Forest, Defendants. First Amended Complaint for Declaratory and Injunctive Relief. 38 pp.

US Environmental Protection Agency (USEPA). 2008. Lost River, California Total Maximum Daily Loads - Nitrogen and Biochemical Oxygen Demand to Address Dissolved Oxygen and pH impairments.

US Environmental Protection Agency (USEPA). 2000. Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria – Rivers and Streams in Nutrient Ecoregion II. Office of Water, Washington DC. EPA 822-B-00-015.

Vollenweider, R.A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. *Mem. Inst. Ital. Idrobiol.*, 33: 53-83.

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